AD-A087 840   CALIFORNIA UNIV LOS ANGELES BRAIN RESEARCH INST   F/G 5/10
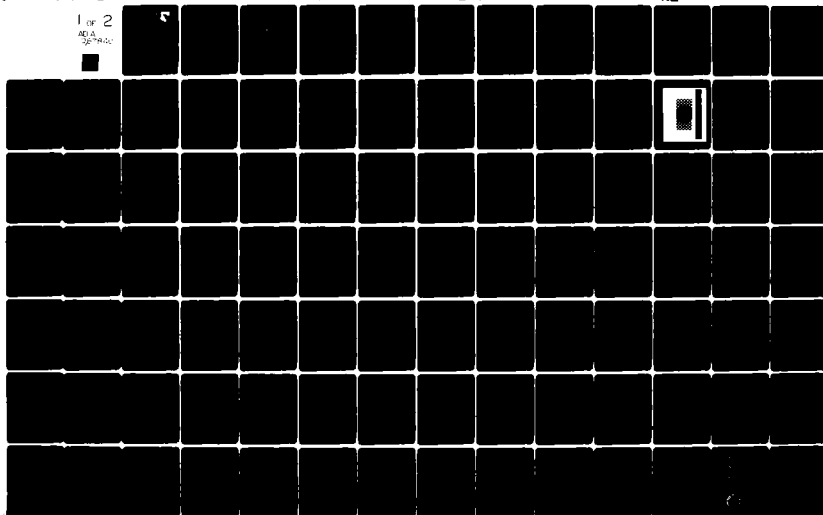   DEVELOPMENT OF NEUROPHYSIOLOGICAL AND BEHAVIORAL METRICS OF HUM--ETC(U)
               MAY 80 S L MOISE   AFOSR-77-3184
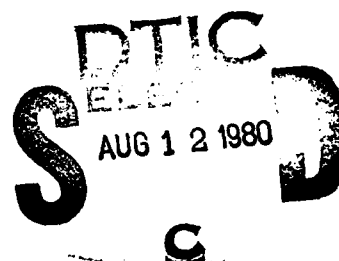UNCLASSIFIED   AFAMRL-TR-80-39   NL

1 OF 2
AD A
A087840

AFAMRL-TR-80-39

LEVEL

HO53018

DEVELOPMENT OF NEUROPHYSIOLOGICAL AND BEHAVIORAL METRICS OF HUMAN PERFORMANCE

SAMUEL L. MOISE, JR.

BRAIN RESEARCH INSTITUTE
UNIVERSITY OF CALIFORNIA
LOS ANGELES, CALIFORNIA 90024

DTIC
SELE
AUG 1 2 1980

C

MAY 1980

THIS DOCUMENT IS BEST QUALITY PRACTICABLE.
THE COPY FURNISHED TO DDC CONTAINED A
SIGNIFICANT NUMBER OF PAGES WHICH DO NOT
REPRODUCE LEGIBLY.

AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

80 8 11 151

NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from Air Force Aerospace Medical Research Laboratory. Additional copies may be purchased from:

> National Technical Information Service
> 5285 Port Royal Road
> Springfield, Virginia 22161

Federal Government agencies and their contractors registered with Defense Documentation Center should direct requests for copies of this report to:

> Defense Documentation Center
> Cameron Station
> Alexandria, Virginia 22314

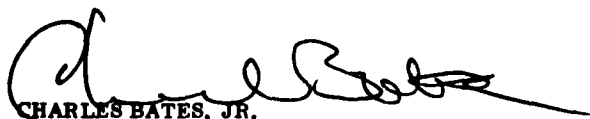## TECHNICAL REVIEW AND APPROVAL

AFAMRL-TR-80-39

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Air Force Aerospace Medical Research Laboratory

DISCLAIMER NOTICE

THIS DOCUMENT IS BEST QUALITY PRACTICABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
AFAMRL-TR-80-39	AD-A087 840	

4. TITLE (and Subtitle)

DEVELOPMENT OF NEUROPHYSIOLOGICAL AND
BEHAVIORAL METRICS OF HUMAN PERFORMANCE

5. TYPE OF REPORT & PERIOD COVERED

Final Report
1 Sept 1976 — 31 Dec 1979

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

Samuel L. Moise, Jr

8. CONTRACT OR GRANT NUMBER(s)

AFOSR-77-3184

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Brain Research Institute
University of California
Los Angeles, California 90024

10. PROGRAM ELEMENT, PROJECT, TASK
AREA & WORK UNIT NUMBERS

61102F, 2313 V1 23

11. CONTROLLING OFFICE NAME AND ADDRESS

Air Force Office of Scientific Research (NL)
Bolling AFB, D.C. 20032

12. REPORT DATE

May 1980

13. NUMBER OF PAGES

152

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

Air Force Aerospace Medical Research Laboratory
Aerospace Medical Division, AFSC
Wright-Patterson Air Force Base, Ohio 45433

15. SECURITY CLASS. (of this report)

Unclassified

15a. DECLASSIFICATION DOWNGRADING
SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Transient Evoked Response, Steady-State Evoked Response, Performance, Workload,
Memory, Eye Movements, Visual System, EEG, Sternberg Task

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A program of research has been conducted to evaluate transient and steady-state visual
evoked response (ER) measures to determine their suitability as metrics for assessing
performance (or workload). One of the major drawbacks of the ER is the necessity for
creating the response by flashing lights (transient ER) or shifting patterns (steady-state
ER) in the subject's visual field. One of the main goals of this program was to explore

(Continued)

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE
1 JAN 73

20. Abstract (Cont'd)

the production of ERs in ways which do not interfere with task displays or performance. A second major goal was to evaluate the ER as a tool for simultaneous measurement of multiple performance factors. This program produced several research directions which have important implications for the study of brain function and practical application of the ER as a performance measure. These directions include generation of steady-state activity with visual stimuli above 75 Hz, and the introduction of a concept of temporal tracking by the brain. Among the results of these studies are demonstrations of correlations between the steady-state ER and fatigue and psychological factors.

Accession for

NTIS GRA&I

DDC TAB

Unannounced

Justification

By

Distribution

Availability Codes

Dist | Avail and/or
Special

A 23

Contents

INTRODUCTION

This document is the final report for the three year AFOSR research program AFOSR 77-3184. When this program began, the stated purpose was to do research which would provide data to begin development of metrics derived from multi-dimensional behavioral and neurophysiological indices which could ultimately be applied across a wide range of tasks to describe human performance. It was envisioned that these might take the form of an "applications handbook" in which boundaries of human performance would be described by these metrics.

The work begun in the first year represented two different approaches to the problem. A methodology was developed for the laboratory study of clutter factors that affect target identification, and the mathematics of Catastrophe Theory were evaluated as a potential metric for describing human performance in multiple dimensions.

The Clutter system is an extensive computer/software package which generates patterns of moving targets and drones on a graphics terminal simulating the movement of real aircraft approaching an observer. In addition to being an ideal methodology for the study of multidimensional factors on human performance, this system provides a timely laboratory research tool for the Air Force to study Clutter factors. This system allowed the examination of behavioral

measures (e.g. reaction time) and changes in the electroencephalogram (EEG) during performance.

An intensive evaluation of Catastrophe Theory was made as it seemed to hold the promise for making tractable in a single metric both behavioral and neurophysiological measures which could be used to predict significant changes in behavior. If such a method were available, prediction of sudden disintegration in performance or attainment of desired skill levels might be possible. We envisioned its potential for evaluating neurophysiological patterns with the goal of predicting conditions under which performance might be expected to change.

The evaluation of Catastrophe Theory led to the inevitable conclusion that it is a technique which had not developed into a useful practical tool. Continued observation of developments in Catastrophe Theory over the last two years has confirmed this impression. The initial excitement over the uses of this theory have all but died out in the research/applications community.

At this time it appeared that the evoked response (ER) of the brain was a potentially valuable neurophysiological indicator of human performance and the external factors affecting performance. It seemed that ER measures might provide metrics for predicting multidimensional human behaviors. The ER is considered by some to be more useful than conventional EEG and other electrophysiological

3

measures in assessing brain function. ER patterns have been shown to reflect functioning of sense organs and cortical and subcortical brain areas (see Regan, 1972 for a summary). These patterns also permit evaluation of the effects of changes in the sensory qualities of a displayed scene as well as the cognitive demands and response requirements of a specific task.

The sensitivity of the ER and its ability to separate cognitive and perceptual factors has led to its use in the investigation of human information processing, the effects of display relevance and cognitive workload, the development of design standards for man-machine systems, and in clinical applications (see Regan, 1972; O'Donnell, 1979, for summaries). The ability to parcel out multiple factors affecting performance from this single measure is potentially one of its most important characteristics for application to real problems in laboratory and field situations.

Given the potential value of the ER, a series of pilot, and open and closed protocol experiments were begun to investigate a series of questions concerning the ER, brain function and performance. Some questions arose from these experiments as they were performed, and provided impetus not only for this research but for other projects in the Neuropsychology Laboratory at AMRL as well.

4

RESEARCH PLAN

The Visual Evoked Response (VER) is perhaps the most studied of the evoked responses and is appropriate for studying factors that affect human operators who monitor visual displays or search over some visual space. The most commonly studied VER is a pulsed response generated by flashing a stimulus. The pulse is allowed to dampen and return to baseline before another "flash" is presented. This will be referred to as the transient ER. If the flashes are presented close together, the pulse does not return to baseline before the next pulse is generated. The ER thus generated follows the frequency of the stimulating pulse and is called the "steady-state" ER. Experiments were designed to examine transient and steady-state ER's to determine their suitability as metrics for independently assessing performance (or workload) and how it is affected by the task environment.

One of the major drawbacks of the ER is the necessity for creating the response by flashing lights or shifting patterns in the subject's visual field, presenting auditory clicks, or the like. It became clear that production of ERs in ways which did not interfere with the task displays or performance, and evaluating the ER as a means of simultaneously measuring several performance factors should provide a solid foundation for the eventual development of multidimensional metrics. In addition, this approach would

provide data which could lead to immediate implementation of ER monitoring techniques in Air Force laboratories and possibly in operational environments. This research thrust seemed potentially useful considering the increasing interest in measuring workload and factors which affect workload on the human operator.

The usual way in which ERs are generated requires disruption of the entire visual field. If the ER could be elicited by part of the visual field (the periphery) so as not to disrupt a visual task requiring the center of the visual field, then the information of the ER might be available with minimum disruption of the primary task. The phase shifting steady-state ER seemed particularly suitable for this and a determination was made if steady-state ERs could be detected when the stimulating source was in the periphery of the visual field. Having shown that these ERs were readily identifiable, an experiment was run to examine the effect of such peripheral stimulation on the transient ER and memory load using a Sternberg task paradigm (Sternberg Surround experiment).

This work with continuously flashing lights led to the suggestion that the steady-state ER might be generated by frequencies above critical fusion frequency. If this were possible, then entire displays might be used to generate ERs at such a rapid rate that the operator would not notice the process. The literature indicates that steady-state activity with sine wave modulated stimuli can be detected up

6

into the range of 50-90 Hz. by averaging techniques. To investigate this possibility, a number of experiments were performed in which modulated white light was presented to subjects over a range of frequencies from 15 Hz to 175 Hz (Fast Frequency Following experiment).

While performing these high frequency visual stimulations, our attention became focused on the ability of the brain to follow changing stimulating frequencies, even when one was presented right after another. Col. Robert D. O'Donnell of AMRL made the suggestion that the brain might be able to "follow" changing external frequencies of stimulation in much the same way that a human operator follows a target with a joystick. If so, this might provide an entirely new way of assessing brain function. In addition, this would open the possibility of describing this kind of brain activity with the well-developed mathematical models of control theory in which there are a number of concepts appropriate to the description of workload, such as remnant and capacity. Therefore an experiment was performed to determine if the brain would follow sudden changes between two frequencies, then another experiment in whch a set of frequencies was used. A third experiment was then run in which subjects performed a demanding task over several hours in order to assess the effects of fatigue on the brain's ability to follow changing stimuli (Temporal Frequency Following experiments).

Given the usefulness of the ER to describe task

variables and task performance, it was of interest to determine if the ER could be used to simultaneously index several variables. An experiment was designed to manipulate cognitive workload (memory load) and stimulus integrity (focus) to see if cognitive and sensory factors could be measured simultaneously (Sternberg/Focus experiment).

One way to generate ERs without using external (exogenous) stimulation is to use a naturally occurring (endogenous) event as the trigger for detecting the potential. One such naturally occurring event which is known to produce ERs is the eye movement. Some of these elusive ERs (sometimes called lambda waves) seem to be related to the movement of patterned stimuli across the retina. It is not known if these ERs carry any useful information about the task environment or subject state. An attempt was made to generate stimulus-relevant ERs triggered by voluntary eye movements. If they could be generated, experiments were planned to determine if they contain information about the stimulus environment and if they could be produced and evaluated quickly (EOG/ER experiment).

Lastly, the literature suggested that eye movements may be useful for providing additional information about task behavior. It was decided to run additional subjects on the Clutter experiment and take eye movement data to determine if it would provide additional information that would help predict subject performance (Clutter experiment).

The following sections detail the conduct and findings of each of these groups of experiments. Due to the quantity of data involved in this program, this document only presents enough detail to describe the main findings. Additional data may be found in the Technical Reports (in preparation) describing each experiment.

Conduct of the Research

The experiments designed for this program were conducted at the Neuropsychological Laboratory in the Human Engineering Division of the Air Force Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio. This well-equipped facility was generously made available for this use by the Air Force and provided an economical and efficient means for conducting experiments for which the investigator's laboratory was not well equipped. An employee was hired in Dayton to perform data collection and the investigator traveled to Wright-Patterson frequently to train the employee and set up experiments. As data was collected, it was sent to UCLA for reduction and analysis. This arrangement has been very satisfactory and permitted a significant quantity of reasearch to be done at minimal cost.

Laboratory Facilities

The laboratory facilities used for this project were located in the Neuropsychological Laboratory at AFAMRL, Wright-Patterson AFB, Ohio. A schematic of the main components of this facility is shown in Figure 1. This laboratory allowed recording of transient and steady-state evoked responses with great flexibility in stimulus presentation, data recording and data storage.

The IAC chamber (Figure. 1) is available to provide RF shielding; however, the quality of recording electrodes and amplifiers has generally made this unnecessary. The Grass AC preamplifiers (Grass P511) were typically used with a bandpass of 0.1 to 100 Hz. The Honeywell one-inch analog tape recorder (Honeywell 5100C) was used to store all EEG, EOG, stimulus and response data for later retrieval and analysis. The Nicolet 1072 signal averager was connected to a Kennedy digital tape deck which was used to store averaged data.
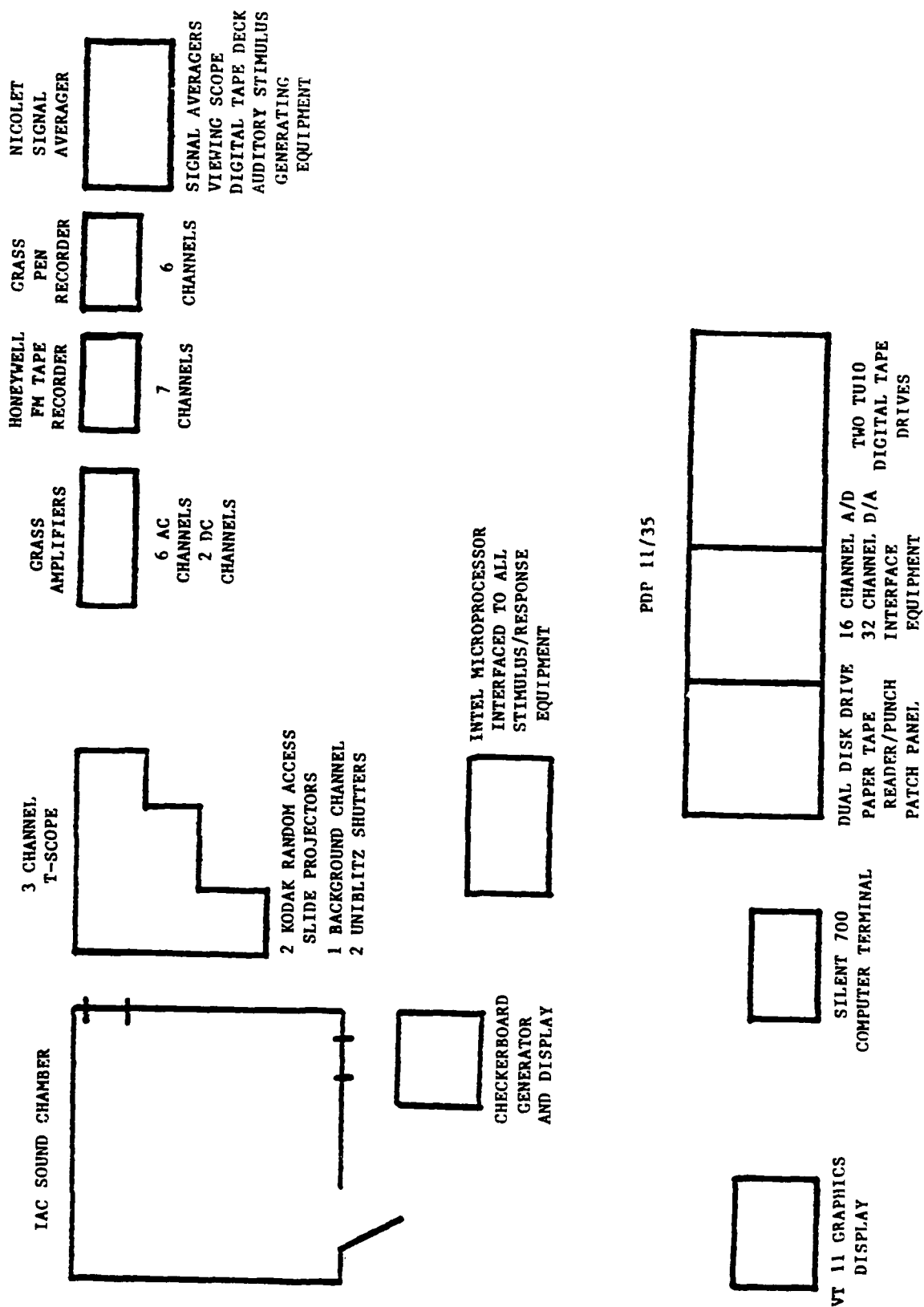
NICOLET
SIGNAL
AVERAGER

SIGNAL AVERAGERS
VIEWING SCOPE
DIGITAL TAPE DECK
AUDITORY STIMULUS
GENERATING
EQUIPMENT

GRASS
PEN
RECORDER

6
CHANNELS

HONEYWELL
FM TAPE
RECORDER

7
CHANNELS

GRASS
AMPLIFIERS

6 AC
CHANNELS
2 DC
CHANNELS

3 CHANNEL,
T-SCOPE

2 KODAK RANDOM ACCESS
SLIDE PROJECTORS
1 BACKGROUND CHANNEL
2 UNIBLITZ SHUTTERS

INTEL MICROPROCESSOR
INTERFACED TO ALL
STIMULUS/RESPONSE
EQUIPMENT

PDP 11/35

IAC SOUND CHAMBER

CHECKERBOARD
GENERATOR
AND DISPLAY

DUAL DISK DRIVE
PAPER TAPE
READER/PUNCH
PATCH PANEL

16 CHANNEL A/D
32 CHANNEL D/A
INTERFACE
EQUIPMENT

TWO TU10
DIGITAL TAPE
DRIVES

SILENT 700
COMPUTER TERMINAL

VT 11 GRAPHICS
DISPLAY

Figure 1. The Visual Response Facility at Wright Patterson Air Force Base.

11

The PDP-11/35 was a key element in the Clutter system developed in this contract, but was not otherwise used for these experiments. The more recent addition of an Intel 8085 development system which has been interfaced with all stimulus generation equipment has provided a flexible and convenient means for controlling stimulus presentations and response handling. In addition to these basic building blocks, special equipment was used as needed and is described in the appropriate sections of each experiment.

Data analysis was performed in the investigator's computer laboratory in the Brain Research Institute of the University of California at Los Angeles. This laboratory contains complete facilities for handling analog and digital data with eventual conversion of all data to digital format for computer analysis. This facility, based around PDP-8/A and PDP-8/I CPUs, includes analog tape drives (Honeywell 7600 and Ampex FR-1400), analog to digital conversion, 7 and 9 track digital tape systems, a floating point processor, Printronix line printer/plotter and 3.32 million 12 bit words of on-line disk storage.

Supporting this hardware is a library of data handling and analysis software developed by the investigator over a period of 10 years. A more detailed description of these facilities appears in Moise and Fields (1978).

The steady-state evoked response has been shown to be useful in assessing the integrity of sensory pathways and can act as a physiological calibration signal (Regan, 1975). It is anticipated that the amplitude of the steady-state evoked response may also provide a means for evaluating other properties of the stimulus environment.

During the search for a way to non-obtrusively and quickly generate ER activity, it appeared that the steady-state might be produced with a minimum of task interference by surrounding the task environment (e.g. a display) with a phase-shifting pattern. Steady-state ERs to pattern reversal are generally thought to be mainly due to macular stimulation (Regan, 1972). Rietveld et al. (1967) compared the contribution to the transient ER of foveal and extra-foveal stimulation by means of a centrally located black disk in a checkerboard pattern. This group concluded that only about 30% of the transient ER is due to stimulation outside the central 3 degrees of the visual field. Because it was unknown if a measurable steady-state ER could be generated by peripheral stimulation alone, an experiment was performed to answer this question.

13

Two subjects (1 male and 1 female) were used in this experiment. Subjects were comfortably seated in a dark enclosure approximately 60 cm from a circular display window. The display window was 17.52 cm in diameter, subtending 6.28 degrees of visual angle. A patterned field covered the stimulus window with vertical bars 0.31 cm wide which subtended a visual angle of 18.0 min. of arc each. This grid was counterphase flickered at 7.5 reversals per second.

Centered in the middle of the pattern field was a circular black disk with a diameter 2/3 the diameter of the display window. The subjects were instructed to stare at the center of the black area while the grid pattern was counterphase flickered. EEG was recorded from vertex (Cz) and occipital (Oz) leads referenced to right mastoid (left mastoid ground). During data collection, subjects were instructed to fixate on the center of the black disk. Spectral analysis was performed on randomly selected 4 second epochs and the average of 10 spectra for one subject (male) is shown in Figure 2.
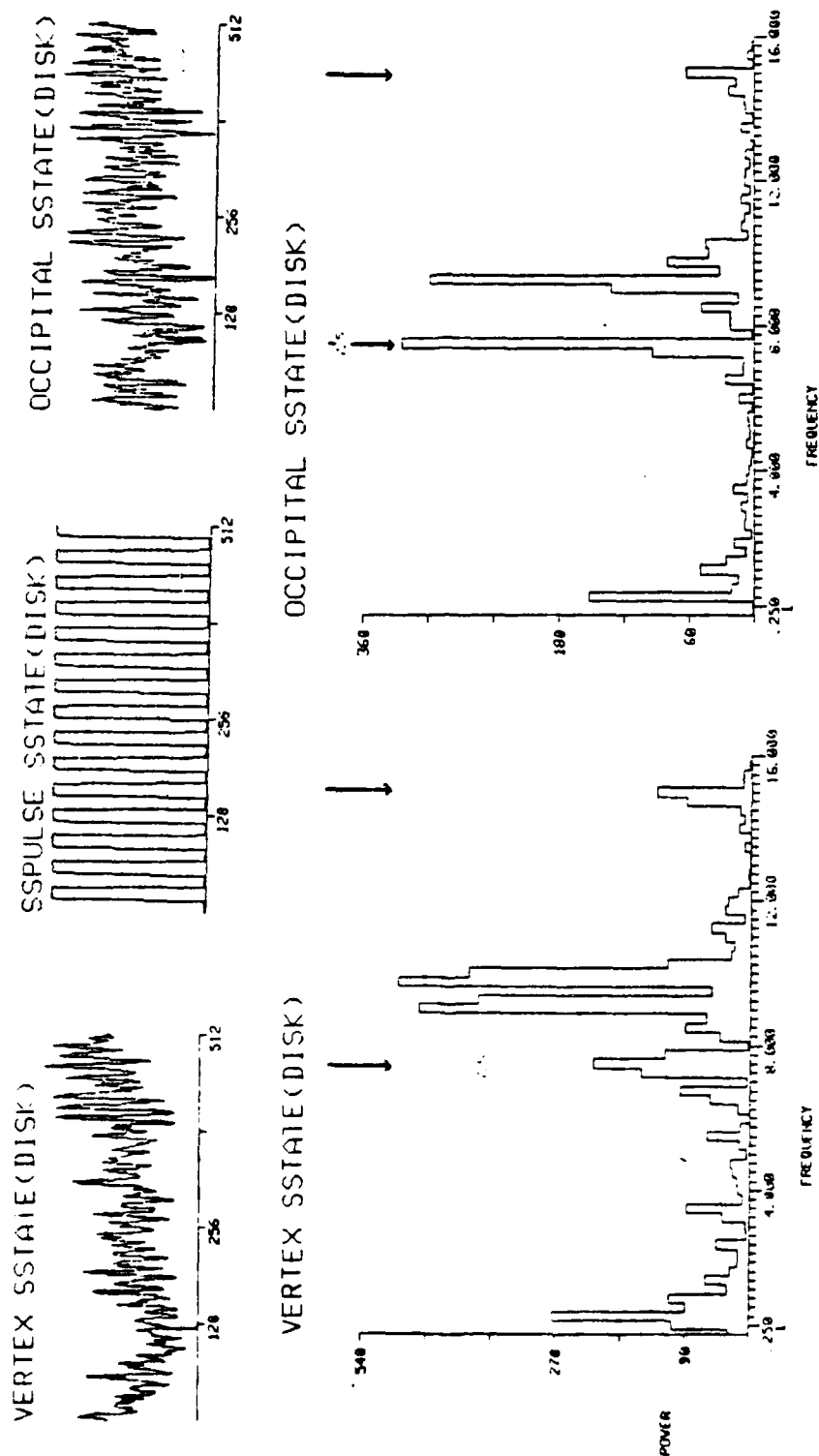
Figure 2 Raw data and spectra for vertex and occipital channels from a subject stimulated by a 7.5 Hz steady-state stimulus (light). The top traces are the raw data averages of 4 sec from 10 trials for vertex (left), occipital (right) and the stimulating light output (center). For the light output, a positive-going pulse (up) means light on, a negative-going pulse (down) means light off. The lower graphs are the spectral power (μv^2/Hz) from 0.25 Hz to 16.0 Hz of the raw data above (vertex on the left, occipital on the right). Arrows point to the spectral output at 7.5 Hz and 15.0 Hz.

15

For both subjects, the occipital channel produced a primary peak of activity at 7.5 Hz. The vertex also showed a clear peak at 7.5 Hz, but this was not the dominant activity. There were also distinguishable peaks at the first harmonic (15.0 Hz) in both channels. The results shown in Figure 2 were replicated by the second subject and compared against conditions with other counterphase flicker rates (6.0 Hz, 10.0 Hz, and 15.0 Hz). In each case an identifiable peak was found at the stimulation frequency and its harmonic that was not present when the stimulation frequency was changed.

It is clear that easily identifiable steady-state activity can be produced by peripheral stimulation. This led to the next experiment in which peripheral generation of the steady-state was used during performance of a cognitive task.

Experiment II

To date, it has not been shown that the steady-state ER reflects cognitive activity. Regan (1977) has argued that the steady-state ER does not contain such information. However, pilot data from the Neuropsychology Laboratory at AMRL has suggested that the steady-state may well be correlated with cognition. Recently, considerable

recognition has been given to the role of cognitive activity in workload and performance variables. It was of interest, therefore, to attempt assessment of the steady-state ER as a means for measuring cognitive activity during task performance.

The well known techniques developed by Sternberg (1969a,b) to study retrieval of information from memory were selected for testing cognitive effects, including memory load and retrieval, on the steady-state. In Sternberg's item-recognition paradigm, the subject is presented with a target set of items (e.g. letter characters called the M-set) which are memorized. When subsequently presented with a test stimulus, the subject must decide whether or not this letter was a member of the positive, or memorized, set or from the negative, non-memorized, set, and make a choice reaction time response accordingly.

Due to the mode of presentation of stimuli in this task, transient ERs may be generated. For this experiment, the transient ER was reduced to a minimum but not completely eliminated. This provided an opportunity to evaluate the effects of steady-state and transient ERs on each other.

Method

Three males and one female, ranging in age from 18 to

17

26 years took part in the experiment. All subjects had experience in the Sternberg task with letter stimuli. Electroencephalographic (EEG) activity was recorded at vertex (Cz) and occipital (Oz) sites referred to right mastoid (left mastoid ground). A circular patch of the scalp, approximately 1 cm in diameter, was abraded at the electrode sites to insure that the measured impedance between electrodes did not exceed 1.5 Kohms. Signals were fed through high-impedance probes into AC preamplifiers (Grass P511) with a bandpass of .1 to 100 Hz. EEG data as well as stimulus and response pulses were recorded on analog tape for later analysis.

Subjects were comfortably seated in a dark chamber approximately 60 cm from a rectangular stimulus field that measured 6.0 cm X 2.62 cm and subtended a visual angle of 5.73 X 2.5 degrees. The stimulus field contained an illuminated circular background 3.30 cm (3.15 degrees) in diameter on which alphanumeric figures 1.12 cm high (1.07 degrees) and 0.98 cm wide (0.93 degrees) were presented. Surrounding the circular background was a continuously counterphase flickering checkerboard display which filled the remaining stimulus field. Check size was 0.26 cm (0.25 degrees) square and was counterphase flickered at 6.0 Hz or 10.0 Hz. Figure 3 shows a typical stimulus configuration. The letter has been outlined and darkened to make it readily visible in the photograph.
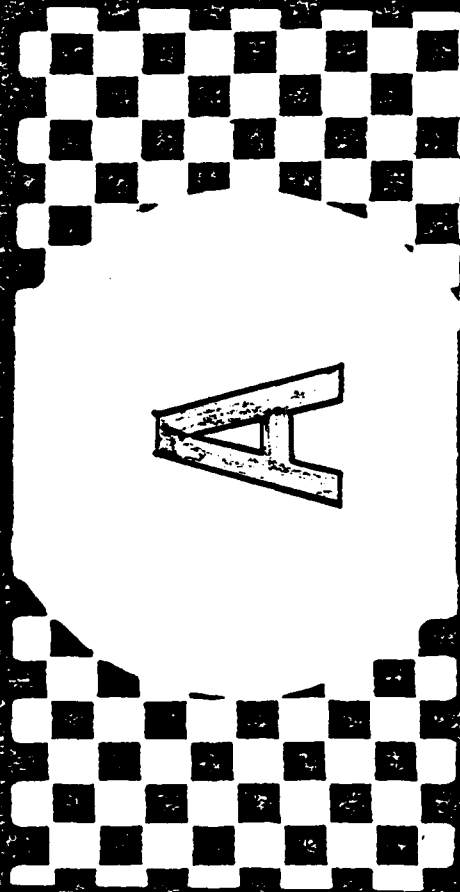
Figure 3. Typical stimulus configuration in the Sternberg Surround experiment. The stimulus to be identified (the letter A) is briefly presented in the center of the field. Surrounding the field is a checkerboard pattern in which light and dark checks alternate position at 6.0 or 10.0 alternations/second.

19

In order to minimize the transient ER when the stimulus letter appeared, intensities of the circular background and the stimuli were adjusted to minimize luminosity change when the stimulus appeared. Intensities of each stimulus letter were measured at the stimulus window and found to be equivalent within the error of measurement. Presentation of the stimulus increased the illumination by only 0.11 ft. lamberts at the stimulus window. Subjects reported that the stimulus seemed to appear and disappear without a noticeable flash.

In this experiment, subjects memorized 1 or 8 letters which constituted the positive set. M-sets 1 and 8 were chosen to give low and high memory load conditions. In addition, a control condition was used in which the subject memorized no letters and was not required to make a response, but only to watch the presentation of letters. The experimenter monitored the subjects visually during control conditions to verify that subjects watched stimulus presentations.

Subjects were told to fixate on the center of the ambient field between presentations and sat with the index finger of each hand on a response key. One key was used to indicate a positive set response, the other a negative set response. The test stimuli were presented for 1 sec through a tachistoscope and the subjects had to decide whether or not the letter character was a member of the positive or

20

negative set and make an appropriate keypress. In accordance with common usage of the Sternberg methodology, subjects were instructed to respond as quickly as possible but to minimize errors. EEG and reaction time data from all trials in which an incorrect response was made, or in which the reaction time was less than 100 msec or more than 1000 msec, were discarded.

Each subject participated in 6 experimental sessions; M-set 1, M-set 8, and M-set 0 (letter stimulus control) with 2 peripheral flicker rates (6.0 and 10.0 Hz) for each of the M-sets above. In each session, 64 trials were presented. For M-set 1 and M-set 8 conditions, half the trials were positive set and half were negative set, yielding a total of 32 trials in each condition. Each session was run without a break and took approximately 30 minutes. The order of item presentations (positive vs. negative) within M-set, and the sequence of M-set presentations to each subject was completely randomized.

Reaction time data were analyed by the Analysis of Variance (ANOVA) in an M-set(1,8) X Steady State Surround (6.0,10.0 Hz) X Positive/Negative set design. Transient ERs were evaluated by the ANOVA and the T-test. Spectra of the EEG were computed (spectral power, uv^2/Hz) and averaged to measure levels of steady state activity. These data were not suitable for analysis by the ANOVA, even after transformation, and the raw data values were tested non-parametrically by the Friedman Analysis of Variance and

21

the Sign test.

Results

A. Response Latencies

Figure 4 shows the mean reaction times (RT), on M-set 1 and 8, for the 4 subjects. As is typically reported in Sternberg task studies, there is a longer RT to negative set than to positive set items; however, this difference was not statistically reliable ($F=4.10$; $df=1,3$; $p<.20$).

Responses to M-set 8 were considerably longer than to M-set 1 which is typical of findings with the Sternberg paradigm. This difference is statistically reliable (ANOVA, $F=22.39$; $df=1,3$; $p<.025$). In addition, RTs were longer when the peripheral steady-state was 10 Hz than when it was 6 Hz ($F=77.43$; $df=1,3$; $p<.01$). An interaction between M-set and steady-state frequency (M-set 1 latencies are about the same for both steady-state frequencies while M-set 8 latencies appear to be longer for 10 Hz steady-state) is suggested by Figure 4, but not supported by statistical analysis ($F=2.77$; $df=1,3$; $p<.20$).
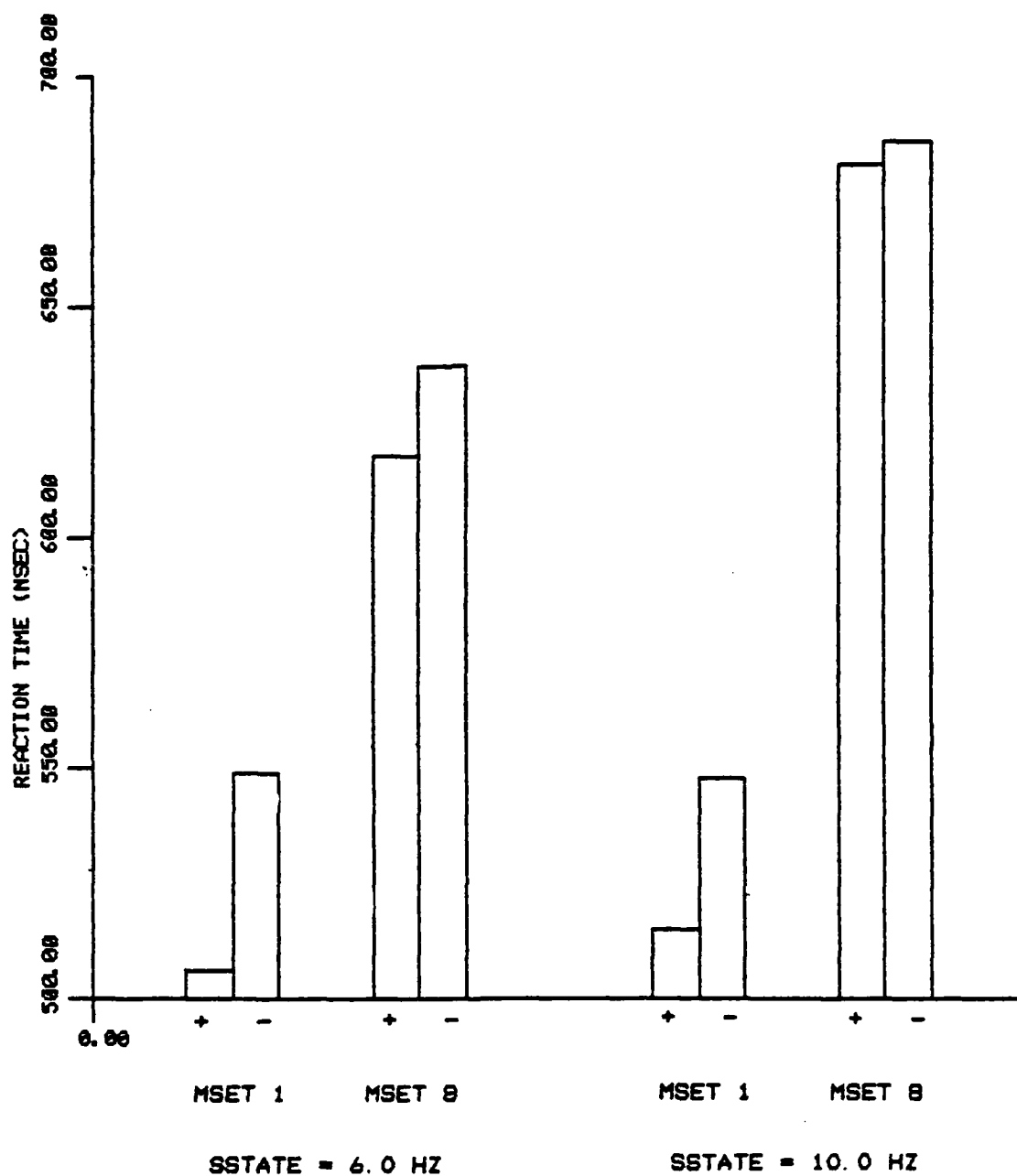
Figure 4. Mean reaction time for 6.0 Hz and 10.0 Hz steady-state stimuli, M-set 1 and M-set 8, and positive (+) and negative (-) sets.

23

The Sternberg task is usually performed with 3 or more M-set conditions in order to perform regression analyses on RTs to determine the slope of a best fit line. This slope is theorized to represent the processing time per item in the M-set. The present study used only 2 M-set conditions that produced latency data and a reliable regression analysis was not possible. Computing the slopes of the line which connects these 2 points for 6 Hz steady-state yielded 16.14 items/msec (positive set) and 12.57 items/msec (negative set). Slopes for 10 Hz steady-state were 23.71 items/msec (positive set) and 19.71 items/msec (negative set). These slopes suggest that 10.0 Hz steady-state interfers with (lengthens) processing time more than 6.0 hz steady-state.

According to Sternberg, the zero-intercept is interpreted as a measure of the mean time taken by the events before and/or after memory comparisons and include the formation of the stimulus representation. The theoretical intercept from the slopes presented above for 6.0 Hz steady-state was 490.0 msec (positive set) and 536.42 msec (negative set). Intercepts for 10.0 Hz steady-state were 491.28 msec (positive set) and 528.28 msec (negative set). While positive set intercepts are almost identical for 10.0 Hz and 6.0 Hz, the 6.0 Hz negative set intercept is 8.14 msec longer than 10.0 Hz negative set intercept.

B. Transient ER

24

Illumination of the stimulus field and stimulus letters was adjusted to minimize the appearance of transient evoked potentials. No detectable transient ER was found in control conditions in which the subjects merely observed the stimuli but made no response. An example with a steady-state surround frequency of 6.0 Hz is shown in Figure 5A. In pilot studies without a steady-state surround, transient ERs produced by small contrast changes are easily seen in the average. It is possible that the presence of peripheral steady-state activity may have reduced or eliminated the usual transient ER under these control conditions.

Typical transient ERs from M-set 1 and M-set 8, with a steady-state surround frequency of 6.0 Hz, are shown in Figure 5B and 5C. In contrast to control conditions, there is a detectable transient ER. However, not all components are readily found. In general, it was possible to identify the second positive peak (P2) and the first and second negative peaks (N1 and N2) in both vertex and occipital channels. These ERs are considerably higher in amplitude than the control condition which implies that these peaks appear when subjects engage in task performance, but not while passively observing the display. The third positive peak (P3) was more difficult to identify, but could not be identified at all in control conditions. It is unknown why P3 should be so difficult to find unless the presence of steady-state activity somehow interferred with its

25

appearance. It is possible that averaging more trials would make this peak more easily observable.

ER amplitudes in vertex and occipital were measured between N1 and P2 peaks (N1/P2) and between P2 and N2 peaks (P2/N2). These amplitudes were statistically compared between M-set (1 vs 8), steady-state surround frequency (6.0 vs 10.0 Hz) and positive/negative set. P3 could not be reliably identified often enough for analysis of N2/P3 amplitudes.

There were no significant differences in ER amplitude for any comparison except one. The occipital P2/N2 amplitude was significantly larger under 6.0 Hz steady-state than under 10.0 Hz steady-state when data was collapsed over M-set and positive/negative set (T-test, t=2.267, df=9, p<.05). In general, there was a tendency for higher (non-significant) amplitudes with 6.0 Hz steady-state than with the 10.0 Hz under all conditions for both vertex and occipital channels.

Latencies of N1, P2, and N2 did not differ under any conditions for either vertex or occipital channels. There was a nonsignificant trend for 10.0 Hz peripheral steady-state to yield longer vertex latencies and shorter occipital latencies than 6.0 Hz peripheral stimulation.
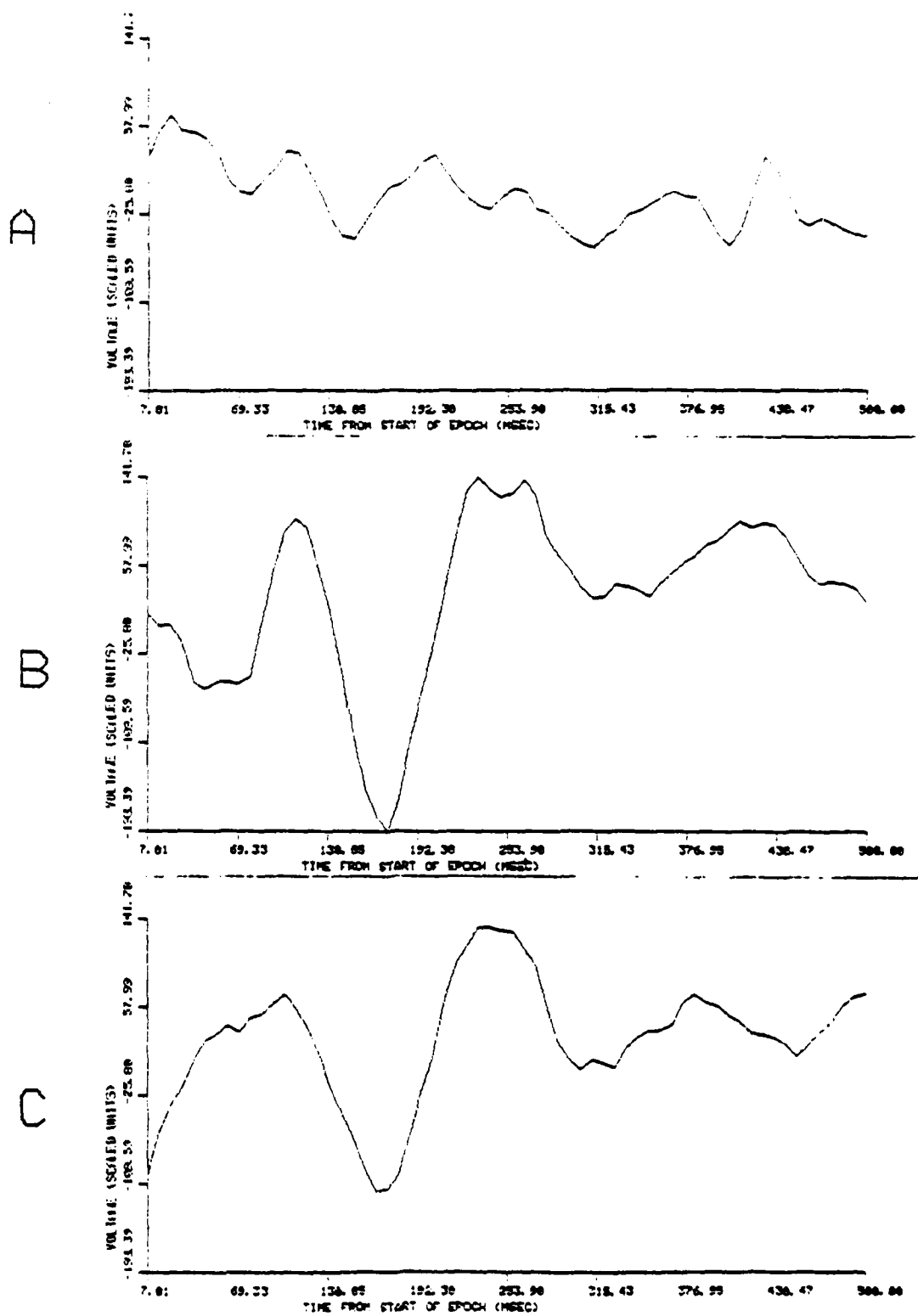
Figure 5. Transient evoked response during M-set 0 (control, A), M-set 1 (B), and M-set 8 (C).

27

C. Steady-State ER

ER differences between positive and negative sets
tended to be larger for 10.0 Hz steady-state than 6.0 Hz.
steady-state in all channels. However, neither this nor any
other difference between positive and negative sets were
statistically significant by parametric or nonparametric
tests, and the data were collapsed over positive/negative
set for the remaining analyses.

The Friedman analysis of variance was applied to
spectral values to assess differences between M-sets in the
fundamental steady-state frequencies (6.0 and 10.0 Hz) and
their first harmonics (12.0 and 20.0 Hz). Figure 6 shows
the mean spectral values at 6.0 Hz. for vertex, occipital,
and the cross spectrum between these channels for M-set 0,
1, and 8. Differences in mean values over M-set are
significant for occipital and cross spectrum (χ^2=6.5; k=3,
N=4; p=.042 for each) and approached significance for vertex
(χ^2=6.0; k=3, N=4; p=.069). In each case, M-set 0 values
are considerably below M-set 1 and 8. With an N of 4, it is
not useful to make pairwise comparisons with an appropriate
nonparametric test as the minimum possible region of
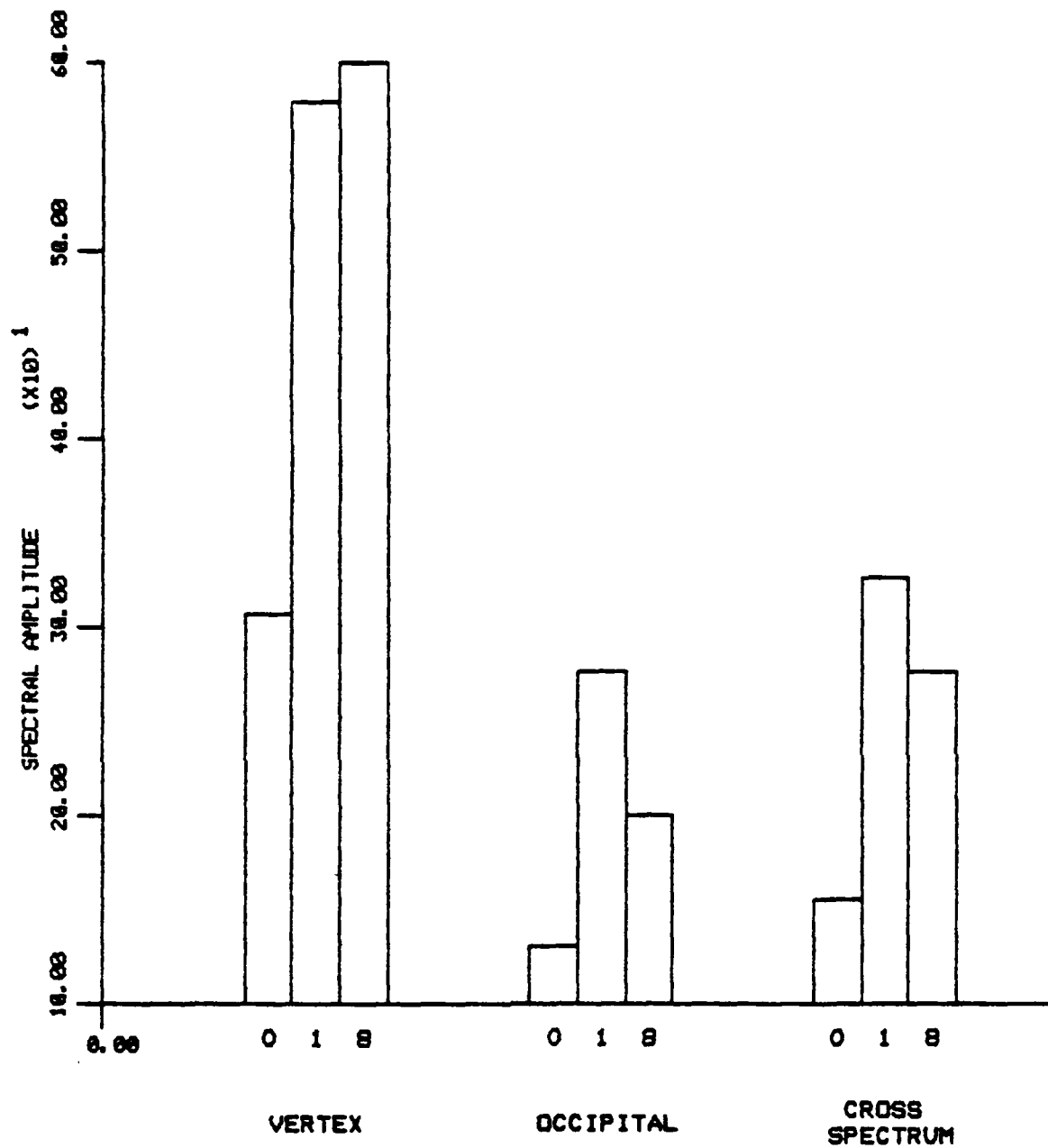rejection is p=.069.

Figure 6. Mean spectral values at 6.0 Hz and for M-sets 0, 1, and 8. Data is from vertex, occipital, and the common activity between these channels (cross spectrum).

Table 1 shows the number of differences in the same direction for each channel. All subjects show lower M-set 0 than M-set 1 values for all channels. Vertex and cross spectrum show lower M-set 0 than M-set 8 for all subjects, and 3 of 4 subjects showed this difference for occipital. M-set 1 was higher than M-set 8 for all 4 subjects in occipital and 3 of 4 subjects in the cross spectrum.

Table 1

Number of differences in the same direction for each channel and each M-set. Differences of direction - 0<1 ; 0<8 ; 1>8. 6.0 Hz steady-state.

	0 vs 1	0 vs 8	1 vs 8
Vertex	4	4	2
Occipital	4	3	4
Cross Spectrum	4	4	3

If one takes the liberty of treating positive and negative set values as separate data sets to increase the number of paired comparisons to 8, then the sign test may be applied. Table 2 shows the results of this treatment. These match very well the patterns seen in Table 1. M-set 0 is significantly lower than M-set 1 for all measures (vertex, occipital, cross spectrum). M-set 0 is significantly lower than M-set 8 for vertex and cross spectrum, but not occipital. M-set 1 is significantly higher than M-set 8 for

30

occipital and cross spectrum, but not vertex.

TABLE 2

Significance levels of the Sign Test applied to pairwise comparisons between M-set conditions with positive and negative set treated as separate data sets. 6.0 Hz. steady-state.

	O vs 1	O vs 8	1 vs 8
Vertex	.035	.004	363
Occipital	.004	.363	.004
Cross Spectrum	.004	.004	.004

There were no significant differences between M-sets for any channel when the steady-state frequency was 10.0 Hz. There was only one significant change over M-set for harmonic frequencies. This was for the vertex at 12.0 Hz (the first harmonic of 6.0 Hz – χ^2=6.5; k=3, N-4; p=.042) and was attributable to M-set 1 being higher than M-set O or M-set 8.

Discussion

Steady-state amplitudes (6.0 Hz) during task activity (M-sets 1 and 8) are higher than during a passive control for vertex, occipital, and cross spectrum measures. The

31

differences could be attributed to motor activity (no response was required for M-set 0), increased attention in M-set 1 and 8 conditions, or to cognitive activity required in M-set 1 and 8 conditions. Differences between M-set 1 and 8 appeared in occipital and cross spectrum and are not likely attributable to motor responses since the same motor actions were required of each. Instead, these differences may be indicative of changes in attention or cognition.

The literature does not provide much help in separating the potential causes of these findings. There has been little work in this area and there are no reports showing steady-state amplitude differences associated with motor activity, attention, or cognitive factors. While the data of this experiment are not sufficient to isolate these potential causes, they have demonstrated that attentional or cognitive factors, and perhaps motor activity, are reflected in steady-state ER amplitude.

In a recent experiment performed at the Neuropsychology Laboratory at AMRL, Dr. Glen Wilson used whole field unpatterned stimuli to generate steady-state activity during a Sternberg task. He used M-sets of 1,4, and 8 letters with a control similar to the M-set 0 control reported here. Steady-state stimulation frequencies were 7.0, 10.0, and 14.0 Hz.

Wilson did not find M-set differences in steady-state amplitudes for the fundamental frequencies, but observed

changes in second and third harmonics. In general, harmonics of 7.0 and 14.0 Hz showed a decrease in amplitude with increasing M-set. Interestingly, neither Wilson's study nor the present one found any change in 10.0 Hz steady-state amplitude, or its harmonics. It is as if this region of the frequency spectrum is more resistant to pertubation during task performance than the other frequencies studied.

It is interesting that differences between M-set 1 and M-set 8 appeared in the occipital and cross spectrum, but not the vertex derivation. Cognitive-attentional differences for transient ERs have typically been reported for vertex and less frequently for occipital recordings.

The cross spectrum differences between M-sets was more like that of occipital than vertex, even though the energy in vertex spectrum was twice that of occipital. This suggests that the relationship between electrical activity in vertex and occipital may be a useful index of attentional or cognitive activity and indicates that vertex parcipitated in this activity even though analysis of its activity showed a pattern different from occipital.

During task performance only N1, P2, and N2 could be reliably identified in the transient ER. The P3, usually associated with cognitive performance, was generally not identifiable. In Wilson's study of whole field steady-state during the Sternberg task, identifiable P3 peaks were found by averaging epochs from 32 trials. P3 latency was found to

be longer at all M-sets when the steady-state frequency was 10.0 Hz than when it was 7.0 or 14.0 Hz. It is possible that under the present experimental conditions (checkerboard pattern, peripheral steady-state stimulation) the presence of steady-state activity interfered with expression of P3. It may also be that including additional trials in each average would reveal the presence of P3.

Of the N1/P2 and P2/N2 amplitudes, no differences were observed related to M-set but there was a P2/N2 difference as a function of steady-state rate. This is consistent with the well known correlation between transient components up to 250 msec and sensory factors such as pattern sharpness and color. In this case the sensory factor may have been temporal (flicker rate).

Response latencies in this study show the expected pattern often seen in Sternberg experiments. Latencies reported here were 50 to 75 msec longer than those reported in other Sternberg/ER studies. This may be due to the presence of steady-state stimulation as 10.0 hz steady-state stimulation did produce longer RTs than 6.0 Hz stimulation.

Sternberg contends that the Y intercept from regression analysis over M-set represents the time required to encode or preprocess the test stimulus into a suitable form for content evaluation and the time needed to organize and execute the motor response. The slope is hypothesized to represent the time per unit item to scan memory and retrieve

34

information for comparator processing.

The small slope values found here are consistent with those found in the literature (O'Donnell, 1975; O'Donnell and Gomer, 1976; Gomer, Spicuzza, and O'Donnell, 1976). These slopes were larger in the presence of 10.0 Hz peripheral steady-state than 6.0 Hz steady-state. This is consistent with Wilson's findings that 10.0 Hz whole field steady-state during the Sternberg task was associated with larger slopes than either 7.0 or 14.0 Hz steady-state. It would seem that 10.0 Hz steady-state, whether peripheral or whole field, blank field or checkerboard, interfers with the hypothesized memory scanning process in this task.

Between this study and Wilson's, it seems clear that steady-state activity around 10.0 Hz produced effects on response latency and P3 transient ER latency that were not produced by lower (6.0 or 7.0 Hz) or higher (14.0 Hz) frequencies. On the other hand, amplitudes of the 10.0 Hz steady-state were not affected by M-set while 6.0 Hz amplitudes were. One might conjecture that these observations are in some way related to the alpha rhythm. This rhythm is known to reach large amplitudes under relaxed conditions, but tends to desynchronize and become much smaller during activation (task performance). This rhythm is easily driven by external stimulation. It may be that such driving couples throughout the brain to produce a robust following that has impact on the functions of neural subsystems involved in performance.

Steady-state evoked responses (ERs) are not usually studied at rates above critical fusion frequency (CFF, 24-56 Hz, depending upon parameters; Regan, 1972). Regan (1972) describes the steady-state visual evoked response (VER) recorded at frequencies up to 50 Hz. Spekreijse (1966) examined the steady-state generated by sine-wave modulated white light at frequencies up to 90 Hz. At frequencies above 50 Hz, the brain's response dropped off rapidly and required thousands of time-locked averages to show the presence of steady-state activity. If such disadvantages could be overcome, fast stimulation could provide an ideal way to generate VERs non-intrusively. If steady-state VERs could be produced by stimuli above CFF, the possibility would exist to have the displays themselves produce VERs by flickering at a rate higher than CFF.

To explore this phenomenon, a white light stimulus modulated at frequencies up to 175 Hz was used. Frequencies above 90 Hz have important implications for theories of visual system function because many current models do not postulate such capabilities.

Apparatus and Procedures

The testing apparatus is detailed in Figure 7. Under test conditions T-scope arm A was open and B was closed so that light produced at light source 1 went to the subject. Under control conditions, T-scope arm B was open and A was closed so that light produced by source 2 went to the subject. In both test and control, the rotating disk was operating and both light sources were on in order to control for possible mechanical or electrical artifacts. Lights from each source were equated for intensity at the viewing window (C) by placing neutral density filters at the opening of the T-scope where light entered from the sources. A light barrier isolated arms of the T-scope and the light sources so no light from one source could enter another arm of the T-scope. Statistical comparisons were made between test and control conditions to insure that differences were due to the presence of steady-state following and not to intensity, mechanical, or electrical factors.

In the initial experiments, light source 1 was an electronic strobe, and the rotating disk was not used. Electrical noise from the strobe severely contaminated the EEG, especially at higher frequencies, and in later experiments was replaced by the rotating disk shown in Figure 7. Several disks were used to explore the effects of on/off cycle on the ER. The disks had four slots, wide enough to produce either 10%, 30%, or 50% on/off cycles.
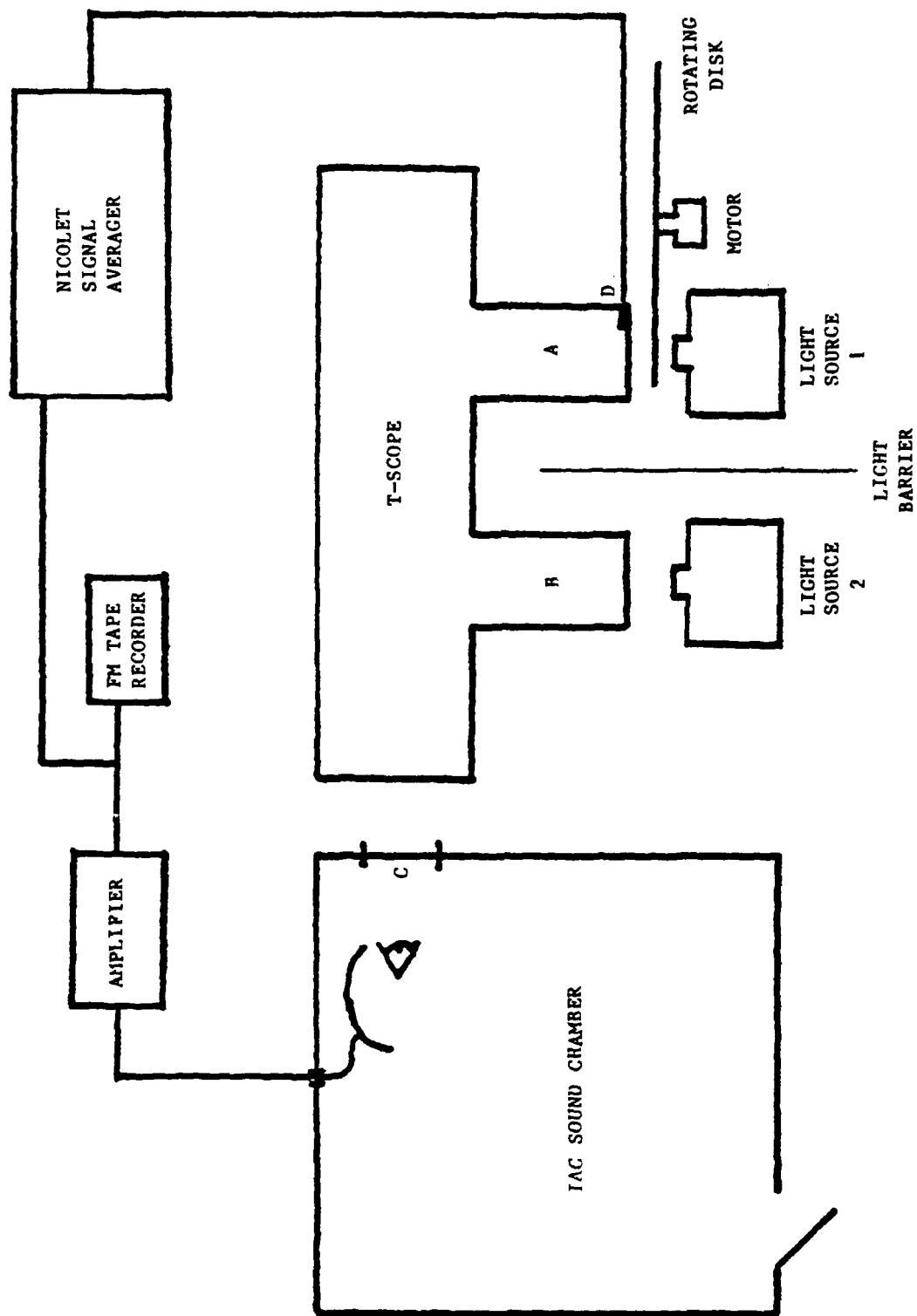
Figure 7. Schematic of testing apparatus used for Fast Frequency Following.

38

A total of 6 subjects between the ages of 18 and 42 were used in these experiments. Each subject was comfortably seated in a dark shielded IAC chamber approximately 60 cm. from the viewing window (C) which was 6.0 X 2.62 cm and subtended a visual angle of 5.73 X 2.5 degrees. The intensity of light at the viewing window ranged from 81.7 to 84.2 ft.-lamberts, depending upon the frequency of stimulation. A much wider field of view was used in preliminary experiments (20 degrees square), but did not improve the amplitude or consistency of the steady-state ER. Both blank field and checkerboard field stimulation were used.

EEGs were recorded from an occipital lead (Oz) referred to right mastoid (left mastoid ground). The amplified signals were recorded on FM analog tape and sent to a Nicolet summing computer. The Nicolet was triggered by the output of a photocell placed in the path of the intermittent light at D in Figure 7. Nine stimulus frequencies were examined from 15 Hz to 175 Hz in increments of 20 Hz.

Identifying steady-state at high stimulus frequencies required a substantial number of averages. Spekreijse (1966) reports 1000 to 10,000 summations necessary for frequencies up to 90 Hz using modulated light. Collecting thousands of samples requires several minutes even at high frequencies. This procedure is extremely fatiguing for the subject, and time consuming if replications are necessary for each

condition. Therefore data was collected in groups of 256 spectra which were averaged. For frequencies of 95 Hz and above, 8 sets of averages were obtained for a total of 2048 samples. Below 95 Hz, 4 sets (1024 samples) were acquired. In addition, at each of the two highest frequencies, each subject was run for several additional sessions in which 4096 samples were collected.

Spectral analysis was used to reduce the raw data into its frequency components. The raw data were input to spectral analysis in two ways. In the first, data stored on analog tape was digitized at UCLA and collected into 1 second epochs time-locked to the photocell output from the intermittent light. Due to limitations of on-line storage and on the address space of the version of Fortran used, it was not possible to handle more than 128 epochs of each of the three data channels (test, control and photocell) without substantial modification of existing software or additional programs. This was particularly true for the highest frequencies tested (above 115 Hz) where we had to digitize at 512 Hz to insure meeting the Nyquist criterion for frequency analysis. In addition, positioning on the digitized photocell pulse channel at these digitizing rates was not as precise as needed. For higher frequencies it was necessary to digitize at 1024 Hz or higher to insure accurate, replicable positioning from pulse to pulse.

In order to facilitate the analysis of larger numbers of averaged epochs digitized at higher rates, the Nicolet

1070 summation computer was used to collect data in blocks of 256 epochs which were stored on digital magnetic tape. Up to 8 such blocks were collected and saved for each repetition of each stimulation condition (Test and Control).

The trade-off for this scheme is that the Nicolet collects a fixed number of points (1024) per epoch. Therefore, as the sampling rate is increased, the time between samples is shorter and the total length of the epoch collected is shorter. In order to insure accurate triggering from the photocell input to the Nicolet, a high digitizing rate was needed, resulting in an epoch length of 250 msec for frequencies above 115 Hz. In order to facilitate comparisons between frequency conditions, 250 msec epochs were used at slower frequencies as well.

The Nicolet tape was input to the UCLA computer facility where spectral analysis was performed on each averaged set of epochs from each condition. The resulting spectra were used to compare test and control conditions by means of the T statistic. Spectral computations performed on 250 msec epochs yielded power density estimates in 4 cycle wide frequency bands. These frequency bands were not usually centered on the stimulating frequency and it was difficult to get precise estimates of the exact frequency of the stimulating light. In cases where the stimulating frequency fell to the side of the frequency band, it is possible that the digitizing process caused the brain response to fall

41

into the adjacent band. Therefore, for each frequency tested, the maximum value of the spectra was selected from the band containing the stimulation frequency and the bands just above and below this one. To insure that changes thus identified were frequency specific, the first harmonic and an additional, non-harmonic frequency were treated in this way to see if they followed the same pattern.

Results

In no case was there an observable difference in averaged raw data or spectra between blank and checkerboard field stimulation. All results reported here are from the blank field condition.

A. Averaged Raw Data

EEG following at low frequencies (below 55 Hz) is visually obvious in the raw average. Following is still clearly visible at 55 Hz. as shown in Figure 8. This figure shows the average of 1024 traces of 250 msec duration. The top trace is the test condition (T), when the subject observed the intermittent stimulus. The middle trace is the control (C) when the subject observed a non-intermittent light of the same intensity as the intermittent stimulus of the test condition. The difference between test and control

is clear for 55 Hz, but much more difficult to assess for frequencies above this. Figures 9 and 10 are examples of higher frequencies (115 and 175 Hz, respectively). In these figures there may be a difference between test and control but it is difficult to assess how well the EEG follows the driving stimulus, if at all.

B. Frequency Analysis

For frequencies up to 75 Hz, the spectra of 128 1-second epochs clearly showed the presence of 15, 35, 55 and 75 Hz activity in test, but not control conditions. Above this frequency, larger numbers of Nicolet averaged epochs were required. Three subjects participated in experiments specifically designed to produce data for spectral analysis. Due to data loss (tape dropouts and artifacts) only one subject had complete data for analysis. No additional subjects were run at this time for the reasons given in the Discussion section.
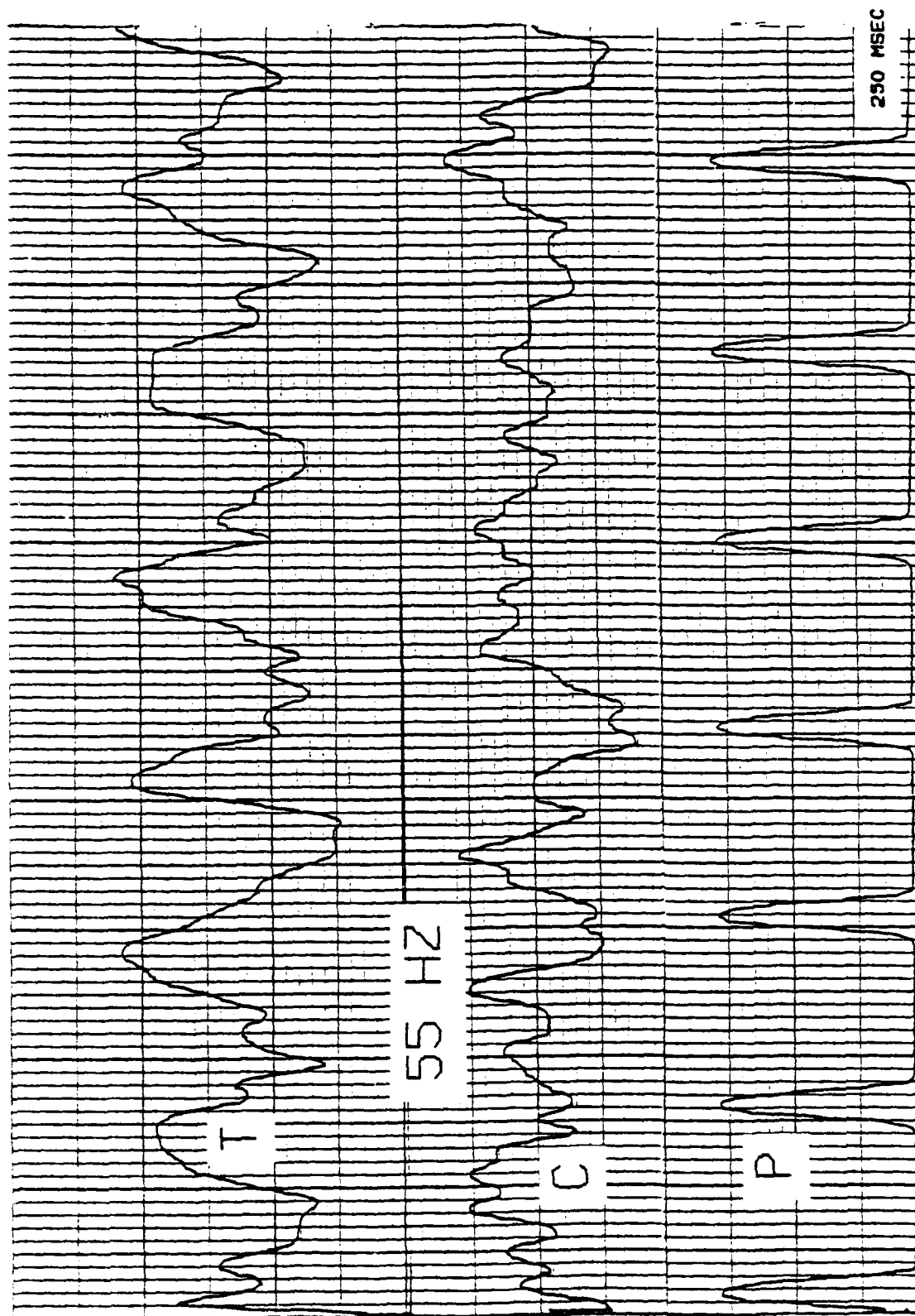
Figure 8. Average of 1024 traces from occipital electrodes, time-locked to the onset of a 55 Hz flashing light. The duration of the traces is 250 msec. T = test condition, C = control condition, P = photocell output (recorded the output of the stimulus light).
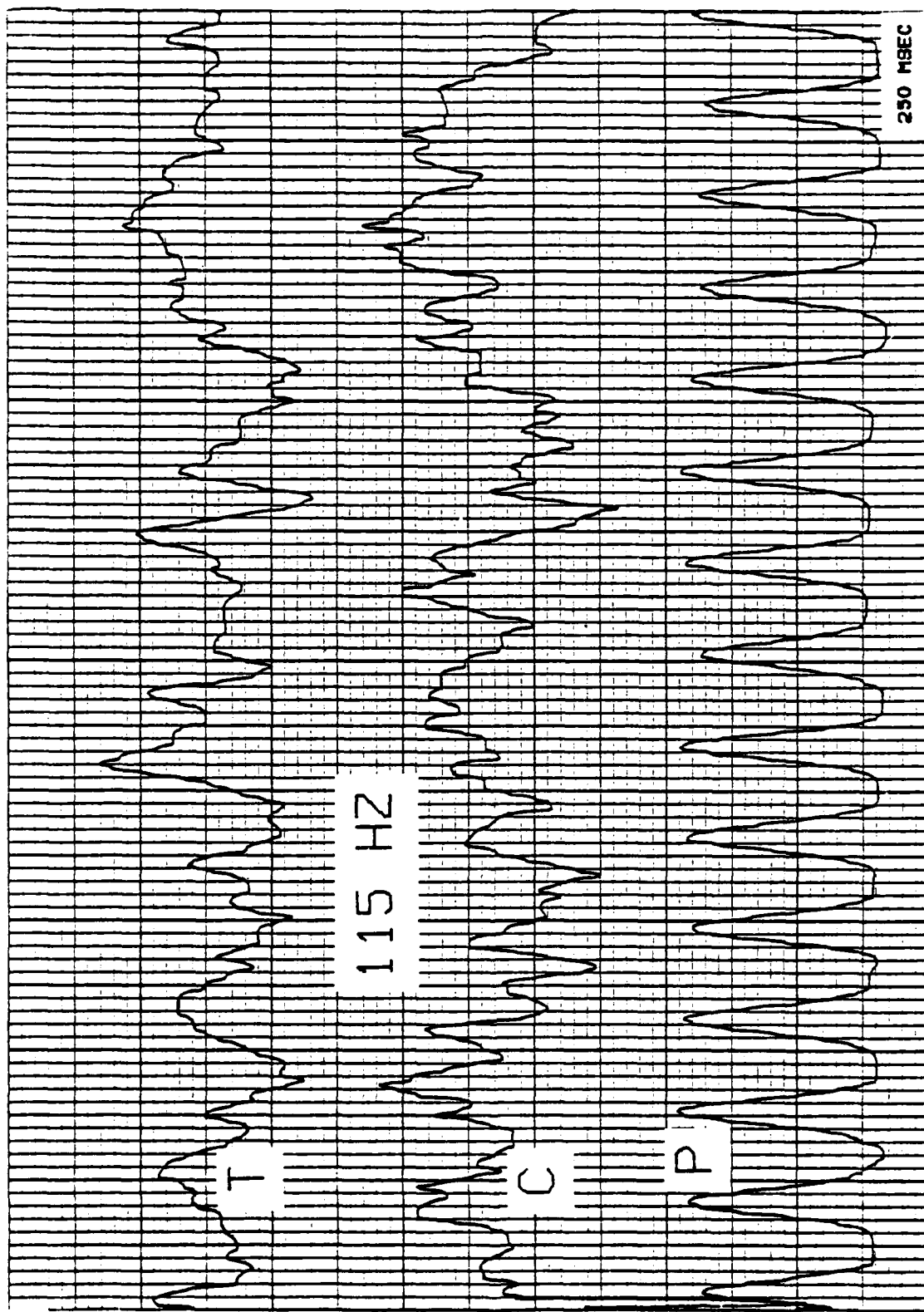
44

Figure 9. Average of 1024 traces from occipital electrodes, time-locked to the onset of a 115 Hz flashing light. The duration of the traces is 250 msec. T = test condition, C = control condition, P = photocell output (recorded the output of the stimulus light).
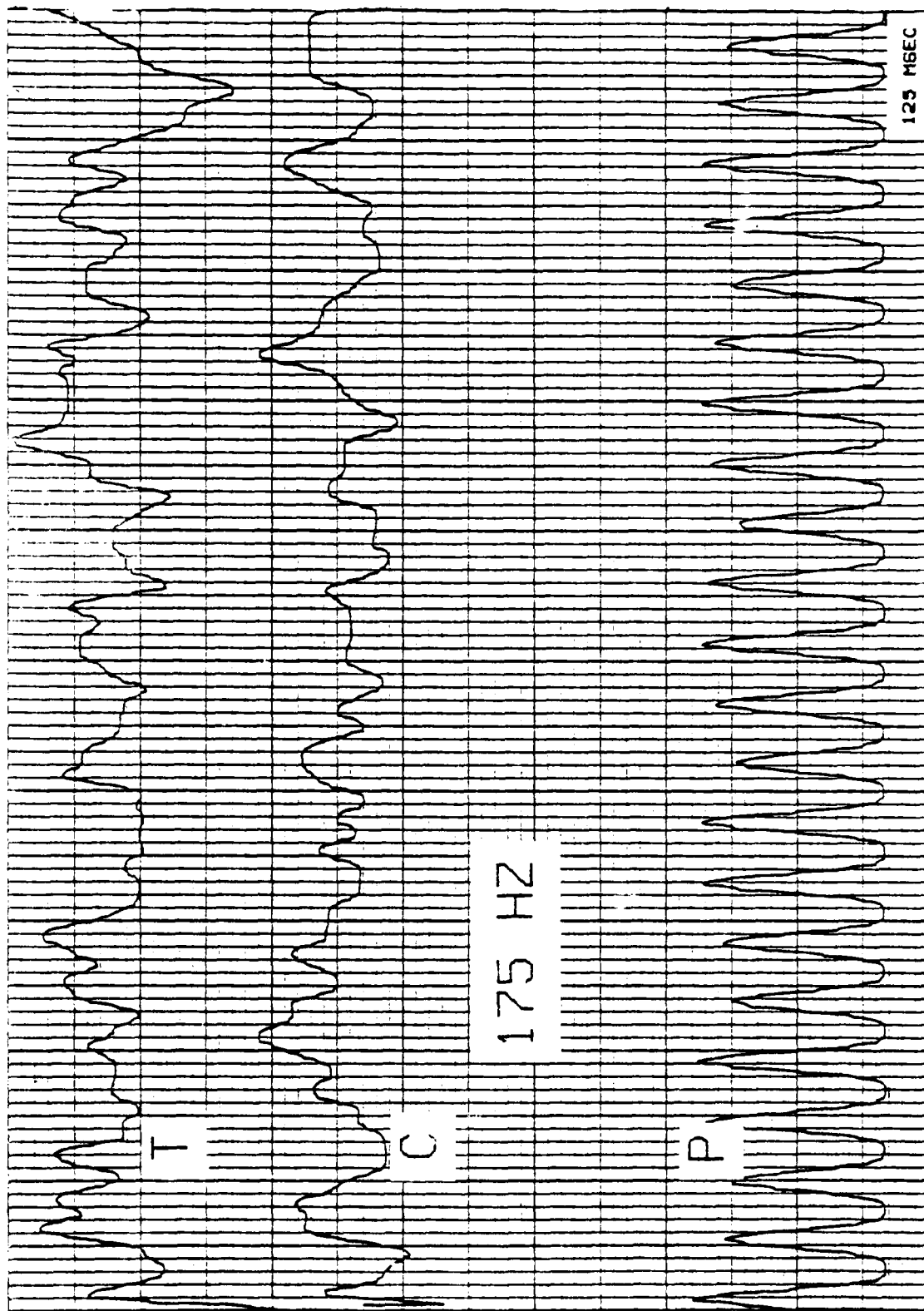
250 MSEC

115 HZ

T

C

P

Figure 10. Average of 1024 traces from occipital electrodes, time-locked to the onset of a 175 Hz flashing light. The duration of the traces is 125 msec. T = test condition. C = control condition. P = photocell output (recorded the output of the stimulus light)

175 HZ

125 MSEC

For statistical analysis, 8 epochs of 256 samples each were collected for 175 and 155 Hz; 6 epochs for 135, 115, and 95 Hz; 5 epochs for 75 Hz and 4 epochs for 55, 35, and 15 Hz. Some data was lost due to tape dropouts and statistical analysis was performed on 4 to 8 epochs for test and control conditions at each frequency. Maximum and minimum values were eliminated in all sets with 5 or more good epochs and the remaining values were input to the T-test.

Spectral analysis of this subject's data revealed statistically valid differences between control and test conditions for 155, 135, 95, 75, 35 and 15 Hz. The mean, standard deviation and t-test results are shown in Table 3 for frequencies of 55 Hz and higher. Spectral values (spectral power from spectral analysis; uv^2/Hz) for the first harmonics of each of these frequencies showed no significant differences for harmonics higher than 150 Hz (75 Hz frequency) as shown in Table 4. Analysis of an additional, non-harmonic frequency (104 Hz) for each condition revealed no significant differences between test and control for any condition.

Table 3

Means, standard deviations and T-tests of spectral values for test and control conditions at each stimulating frequency for Subject #3.

Frequency (Hz)	Test Mean (Std Dev)	Control Mean (Std Dev)	T	DF	p<
175	3516 (2725)	1364 (578)	1.727	10	.100
155	5278 (922)	2984 (844)	3.891	9	.005
135	1714 (266)	878 (51)	5.347	6	.001
115	1485 (1593)	1603 (1731)	0.262	8	.400
95	2556 (833)	4146 (584)	3.124	8	.010
75	7446 (2038)	2497 (268)	3.404	4	.025
55	26731 (9420)	4440 (2399)	3.243	4	.025

Table 4

Means, standard deviations, and T-tests of spectral values at the harmonics of the stimulating frequencies for Subject #3.

Frequency (Hz)	Test Mean (Std Dev)	Control Mean (Std Dev)	T	DF	p<
350	404 (223)	355 (182)	0.382	10	.400
310	459 (185)	1115 (758)	1.706	9	.100
270	281 (160)	463 (194)	1.251	6	.250
230	397 (242)	498 (117)	0.745	8	.250
190	942 (456)	644 (376)	1.011	8	.250
150	1069 (108)	403 (53)	7.767	4	.001
110	6917 (254)	2864 (284)	10.637	2	.005

These data strongly suggest the existence of visual following of intermittent stimulation below 75 Hz and at least at some frequencies above 75 Hz for the one subject tested at those rates. Not all of the frequencies examined showed this effect, suggesting that there may be temporal windows in which the brain is selectively sensitive.

At this point it was clear that the data showed some effect at high frequencies. However, the effect appeared more subtle and intermittent than had been originally postulated. It was apparent that improvement in the data collection procedure would be necessary if this phenomenon were to be investigated in much greater detail. In particular, a hardwired spectrum analyzer capable of finer resolution would be a considerable aid. Independently, the Neuropsychology Laboratory at AMRL had ordered a spectrum analyzer with the desired characteristics. It was decided to wait until this instrument was available to continue investigating this phenomenon. The data tapes will therefore be made available to this laboratory for further analysis as appropriate.

O'Donnell and Wilson (1980) report that there are frequencies of peak ER sensitivities to stimuli in the band from 38 to 64 Hz. The present data extend the concept of peak sensitivities to higher frequencies. Regan (1968a) and

Spekreijse (1966) first suggested the presence of peak temporal sensitivities in the visual system. It is unknown what these sensitivities mean in terms of visual function. Frequencies which are followed by the visual system could represent optimal conditions for neural functioning. Perhaps human performance would be enhanced, or degraded, if stimuli or ambient illumination were presented at these frequencies rather than 60 Hz or 120 Hz typically used.

O'Donnell and Wilson also showed that amplitudes from 50 to 56 Hz showed evident enhancement with each subject showing a different, but well defined peak amplitude response within this range. As they point out, these results are important from a practical point of view in that any attempt to use high frequency steady-state evoked responses, where grouped data may be used, it may be important to determine the peak frequency for each subject. It may be that individual differences will be even more important at the higher frequencies of the present study. It will be important to determine whether individual differences in peak sensitivities are correlated with differences in neural system characteristics.

It is impressive how quickly the brain apparently
begins to follow rhythmic visual stimulation in studies of
steady-state activity. Averaging about 30 consecutive
time-locked epochs is usually sufficient to reveal
steady-state activity. Frequency analysis of ten 4-8 second
epochs is generally sufficient to show steady-state
activity. Changing the frequency of stimulation seems to
entail no particular difficulty for the brain to follow and
the new frequency is usually established well enough to be
detectable within a few seconds. Lt. Col. Robert O'Donnell
of the Neuropsychological Laboratory at AMRL suggested that
the brain might be able to track changes in externally
generated frequencies much like a human operator tracks a
moving object in standard tracking tasks. If brain tracking
can be demonstrated, and if this tracking can be described
by the mathematical models of tracking theory, then brain
tracking may be useful as a secondary task (no overt
response is required) to measure workload or reserve
capacity. This would be particularly useful if the
steady-state can be generated in such a way that primary
task activity is not disrupted.

Perhaps the most important aspect of this suggestion is
that it would provide a new avenue for investigation of

brain function. An entirely new research approach would be available to determine if neural function could be indexed by the ability to follow changing temporal inputs.

One of the most obvious differences between this approach and standard tracking tasks also presents the most difficult barrier to use of brain following as a research tool. Typical tracking tasks are spatial, and a target, which may be located in 2 or 3 dimensions (depending upon the task), typically must be followed by a cursor, also located spatially. The distance between the target and cursor is well defined mathematically and provides a measure of the accuracy of tracking. The speed of the target may also be manipulated, but the basic measure remains the distance (and perhaps orientation) to the target over time.

In the proposed brain following, the dimension being measured is temporal, not spatial, and the central questions are how to measure continuous changes in frequency and how to measure the temporal differences between the driving stimulus and the brain's response. Several techniques exist for detecting and following selected frequencies in random data within certain narrow ranges. Phase-locked loops (Nirenberg, Hanley, and Stear, 1971; Viterbi, 1966) follow the dominant frequency over a narrow band. Unfortunately, the frequency of interest may not always be the dominant one and this method is unlikely to provide an immediate solution.

Complex demodulation (Childers and Durling, 1975; Chirlian, 1973; Chu, 1969) is a means of tracking the amplitude and phase relationships of a given frequency over time. This technique represents bandpass signals as lowpass signals. The outcome of a complex demodulate is equivalent to that obtained by in-phase and in-quadrature filtering, phase-locked loop processing, and Hilbert transform methods, but is achieved with greater computational efficiency. The steps involved in a complex demodulation performed at the investigator's computer facility are as follows:

1) Determination of a center frequency. This can be done either by examining the power spectrum for interesting peaks or by selecting a frequency of a priori theoretical interest. Caution must be exercised in using the power spectrum because irregular bursts of activity at a given frequency will not contribute power to the spectrum.

2) Frequency translation. After demeaning, the time series x_k is frequency shifted by the modulation theorem of Fourier analysis $\hat{x}_k = x_k \exp(-i \, \omega_c \, t)$ so that the center frequency is translated to the origin.

3) Lowpass filtering. The translated series x is now sharply filtered using an Ormsby filter, convolving the series with a set of previously calculated filter weights, m,

$$Z_k = a_i \, x_{k+i}$$

These weights are calculated by an interactive program to test the efficiency of various combinations. The number of filter weights necessary are first estimated and both the raw and smoothed versions in both frequency and time domains are then viewed.

4) Calculation of phase angle. The instantaneous phase angle of

$$\phi_k = \tan^{-1} \left(\frac{Im \ (z_k)}{Re \ (z_k)} \right)$$

can now be calculated.

5) Remodulation. Z_k is now remodulated to give a time history of the bandpass signal.

$$R_k = Z_k \ exp(i \ \omega_o \ t)$$

If ω_c has been accurately estimated, the phase plot will be flat. A positive slope indicates an underestimated ω_o, a negative slope an overestimated ω_o. Thus it is possible, through successive approximations, to determine the exact center frequency of the bandpass signal.

The first time derivative of the phase angle gives the instantaneous frequency of the process, i.e. the moment to moment shift of the center frequency within the bandwidth of

the Ormsby filter. These moment to moment changes are determined by the dominant frequency within the filter bandwidth which is not necessarily the frequency of interest. In addition, as the filter bandwidth gets wider, the output of the demodulation is much more difficult to interpret. An Ormsby filter with a 1 Hz bandwidth was used in the present study. A bandwidth less than 1 Hz did not improve resolution of the process. Center frequencies were chosen to match the frequencies of the steady-state stimulation.

Regan (1966, 1970) has described a device which essentially performs complex demodulation to provide a continuous record of the amplitude and phase relationships between input or idealized waves of single frequencies. In order to track changing frequencies, perhaps a set of such instruments, each adjusted to a different frequency, would provide a set of outputs, the envelope of which would be a measure of following. Such a device was not available at the time this experiment was performed but a complete complex demodulation software package was developed which allowed multiple passes on recorded data specifying a different frequency to be tracked each time.

In order to investigate the brain's tracking ability, experiments were run in which the counter phase alternation frequency of checkboard patterns was systematically changed Discrete step changes in frequency were used to maximize the identification of brain changes. The transition points where

56

the frequency was changed were examined to determine the characteristics of brain activity at those times. This was done for a set of 4 frequencies in Experiment I. One pair of frequencies was then used to investigate effects of fatigue on the steady-state activity of the brain (Experiment II).

Experiment I

Baseline steady-state activity was obtained from 4 subjects at 6.0, 7.5, 10.0, and 15.0 Hz to establish their ability to produce steady-state at these frequencies. Clear steady-state could be seen by time-locked averaging of 30 trials for each of the subjects. Frequency analysis revealed steady-state activity when 10 raw data epochs of 4 seconds each were averaged, then spectrally analyzed. In general, all subjects showed the clearest following (highest spectral amplitudes) at 6.0 and 7.5 Hz.

Each subject was then presented with a series of random frequency changes from the set of 4 frequencies listed above (the test set). The time between changes in frequency was varied and took the values 18 sec, 9 sec, 6 sec, and 3 sec. In all cases, time-locked averages revealed that subjects were able to generate steady-state activity at a given frequency before transition to the next frequency. Results at all time periods were the same and a 6 sec period between frequency changes was selected for use in the experiments

57

which followed. This much time insured enough data for warm-up and cool-down of the complex demodulation filter while providing several seconds of data for tracking frequencies across each transition (see the description of analysis procedures below). The present experiment was then performed to investigate the behavior of the brain at transitions between pairs of frequencies.

Equipment and procedures

Due to difficulties with stimulus generation and data collection, data from 1 subject (male) was unusable. Subjects were comfortably seated in a dark, soundproof chamber. They were approximately 60 cm from a circular display 17.52 cm in diameter subtending 16.28 degrees of visual angle. On this display was a checkerboard pattern with checks 0.26 cm wide, subtending a visual angle of 15 minutes. The stimulus generator was capable of alternating the light and dark areas of the checkerboard over a range of frequencies, including the ones in the test set. Subjects were instructed to fixate on the center of the display and to minimize head movements and blinking while data was being collected.

Electrodes were placed on the scalp of each subject at the vertex (Cz) referred to right mastoid and on the midline occiput (Oz) referred to right mastoid (left mastoid

ground). At the start of each test day a circular patch of the scalp, approximately 1 cm in diameter was abraded at the electrode sites to insure that the measured impedance between electrodes did not exceed 1.5 Kohm. EEG data was recorded on FM tape and digitized at UCLA for frequency analysis. The Nicolet signal averager was used to provide stimulus-locked averages of the EEG data (see section on facilities for a more complete description of recording equipment).

Each test session consisted of 60 alternations between pairs of frequencies with each frequency lasting 6 sec before switching. In the case of arbitrary frequencies A and B, 60 alternations produced 30 transitions from A to B and 30 transitions from B to A. The pairs of frequencies used are shown in Table 5. Data collection for each pair of frequencies required approximately 6 minutes. All 4 frequency pairs took about 45 minutes to complete. Each subject returned for a second day of testing in which the same conditions were repeated.

Table 5

Transition frequency pairs (alternations per second)

FROM	TO	FROM	TO
6.0	7.5	7.5	6.0
6.0	10.0	10.0	6.0
6.0	15.0	15.0	6.0
10.0	15.0	15.0	10.0

Data analysis

Analyses were performed on four second epochs beginning 2 seconds before the frequency change. Since there was a total of 60 reversals in each session, there were 30 trials available for changes from lower to higher frequencies and 30 trials for changes from higher to lower frequencies. Time-locked averages centered on transition points were used for visual examination of the raw EEG. Quantitative evaluation was performed using complex demodulation to follow each of the 2 frequencies, and their harmonics, used in each test session.

For each epoch, 2 complex demodulation analyses were run; one at the steady-state frequency which was present at the start of the epoch, but stopped at the transition point (stopping frequency), and one at the frequency which was not present at the beginning of the epoch, but started at the transition point (starting frequency).


If the brain followed the frequency of stimulation perfectly at frequency A, and frequency A was stopped in the middle of some epoch, its resultant complex demodulate amplitude function would appear as in the top graph of Figure 11. Similarly, if frequency B were started in the

middle of the epoch, its output would look as in the bottom graph of Figure 11. In normal EEG activity, there is always some activity present at all of the frequencies used in this study, and there are few transitions as clear as those shown in Figure 11.

In order to get a quantitative measure of the time at which the brain starts or stops following the stimulus, a variety of approaches were used, including measuring changes in the slope of the phase angle. The most easily identifiable and reliable measure, and the one selected for analysis, was the maximum slope of the amplitude function in the vicinity of the actual change of frequencies (point b in Figure 11). A number of measures were derived from these values and used to evaluate changes due to frequencies in this study, and to fatigue in the second study.

An extensive, single-trial analysis was done by applying complex demodulation to individual epochs. Examination of 120 epochs showed that the frequency response was not clear enough for identification of transition points with any certainty. Therefore, trials were averaged to improve signal to noise ratio.
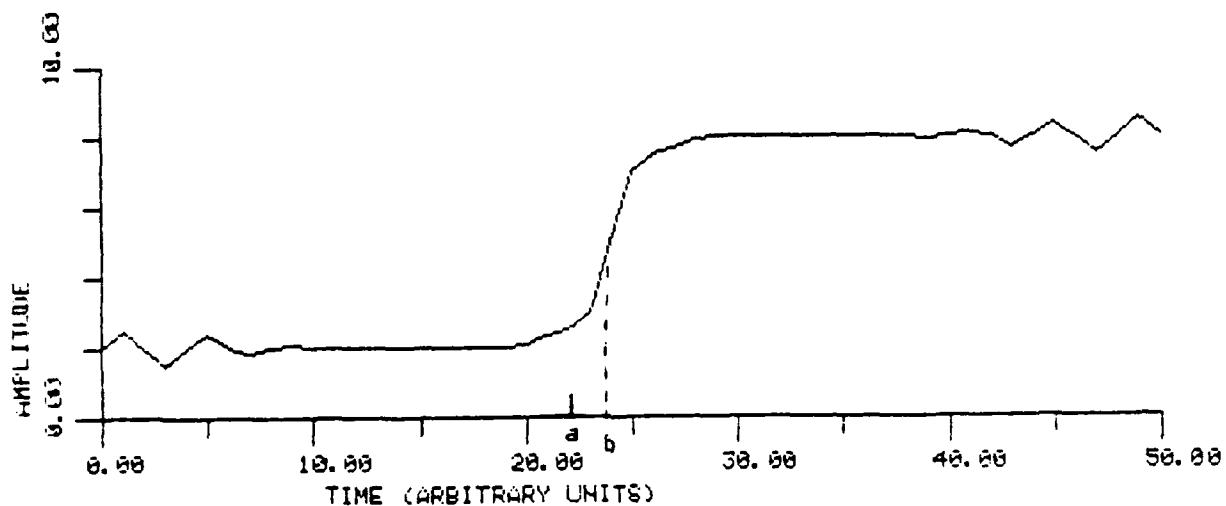
CENTER FREQUENCY A
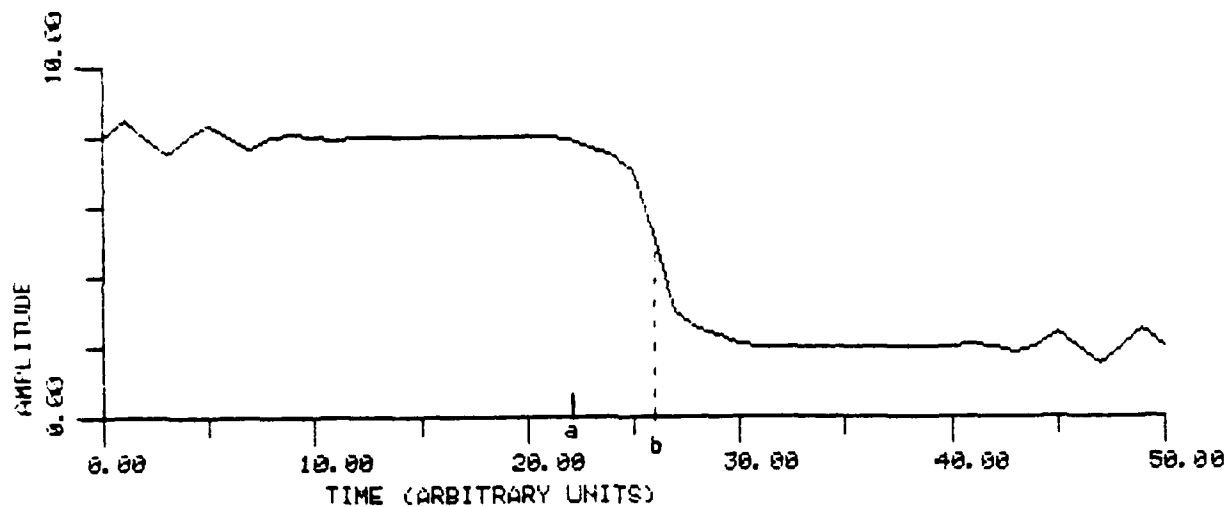
CENTER FREQUENCY B

Figure 11. Idealized output of the Complex Demodulation when
the frequency changes from A to B at point a. The top curve
shows the response of the demodulation with center frequency
A. The bottom curve shows the response of the demodulation
with center frequency B. The first and last 8 to 10 time
units in each curve "rings" due to warm-up and cool-down of
the demodulation filters. The point of maximum slope
(excluding warm-up and cool-down periods) in each curve is
at b

62

There are two averaging techniques that might have been used on these data. The first was to perform complex demodulation on each of the 30 4-second epochs in each condition, then average the output of the demodulation. The second method was to average the 30 4-second raw data epochs, then perform complex demodulation on the resultant average. Experience with each of these methods has shown that the former provides better estimates of the behavior of the frequency of interest, but takes considerably longer to perform.

For both this experiment and the one described in the next section, there were over 4300 epochs analyzed. The time to perform all necessary data extraction, manipulation, and analysis is considerable. With the UCLA PDP-8 computer facility, this would have taken approximately 60 days of computer time (8 hours a day) if we had performed complex demodulation on each individual epoch. This lengthy computation load could be reduced to an acceptable level by the use of any of a number of fast current generation computers, perhaps in conjunction with an array processor, or hardwired analyzers such as that described by Regan (1966, 1970). This projected computation time was an unacceptable commitment to make at the UCLA facility as the computer was necessary for other aspects of this grant concurrently. Therefore, it was decided to average the raw data first, then perform demodulation. Even this required approximately 22 full days of computer time.

Both the raw average and frequency analysis clearly showed steady-state activity in the occipital channel for all subjects. Vertex recordings did not show steady-state activity. This is very surprizing in view of the fact that other investigators in the Neuropsychology Laboratory, using the same equipment and similar procedures, have obtained good parietal steady-state at these frequencies. A different group of subjects who were used in Experiment 2 of this study also did not have good vertex steady-state. It is not known why these subjects did not produce adequate vertex steady-state. It is possible that the vertex recording equipment was not operating properly. Whatever the reason, only one subject produced an identifiable vertex steady-state and the following results are based only on the occipital EEG.

Figure 12 shows 2 seconds of an average of 30 trials from the occipital channel in which the stimulating frequency was changed from 15.0 alternations/sec. to 6.0 alternations/sec.. As can be seen in the left side of the graph the EEG follows 15.0 alternations/sec. (15 Hz brain rhythm) very closely. As soon as the transition is made to 6.0 alternations/sec. the occipital EEG seems to lock onto this new frequency within 1 or 2 cycles. There is a

suggestion, in the first few cycles after the change, of remnants of the 15.0 alternations/sec. frequency.

Complex demodulation at the stimulation frequencies clearly revealed the transition between frequencies as may be seen in the amplitude plots of Figures 13-16. In these figures, only the middle 2 seconds of each 4 second epoch is shown to eliminate the 0.5 to 1 seconds required by the complex demodulation filter to warm up and cool down. The demodulation algorithm used here provides an estimate of the amplitude (and phase) of the center frequency using a non-realizable filter. This permits the algorithm to "read the future" by looking ahead to the entire data sequence before it computes the estimate. That is why the transition from one frequency to another appears to start before the occurrence of the actual switch in stimulation frequency.

The phase output of this procedure depicts the relationship between the center frequency and an ideal sine wave at that frequency. If the slope of the phase is flat, the center frequency has been accurately estimated. That is, the center frequency specified to the algorithm is in fact the primary activity within the passband of the filter. All phase outputs in this study suggested that the center frequencies were chosen accurately. A sudden sharp change in slope of the phase function has been interpreted as an estimate of the arrival of a wave process. In the present experiment there were often sharp transitions in phase after one frequency stopped and another began. These generally

65

occurred considerably after transitions in amplitude and do not seem to represent the acquisition or loss of either driving frequency. This may be because the frequency transitions are very large compared to the filter passband and because each frequency is never completely missing from the spectrum in EEG data. Activity at any frequency (especially slower ones) may be present at a relatively high level before or after the driving stimulus has changed.

The amplitude output seems to reflect the brain's changing wave process as seen in the raw averages. In an attempt to quantify the changes from one frequency to another, the maximum slope of the demodulation output in the vicinity of the actual stimulus change was computed. A number of measures were computed from the maximum slope value including: 1) the time from stimulus transition to maximum slope of the frequency which stopped (the time between a and b in the upper graph of Figure 11), 2) the time from stimulus transition to maximum slope of the frequency which started (the time between a and b in the lower graph of Figure 11), and 3) the time between maximum slopes of the starting and stopping frequencies (the difference between b in the upper and lower graphs of Figure 11). These measures were computed for all transition pairs shown in Table 5. Statistical evaluation of the differences between transition conditions for each of the computed measures was made with the Analysis of Variance (ANOVA), the T-test, and nonparametric statistics.

66
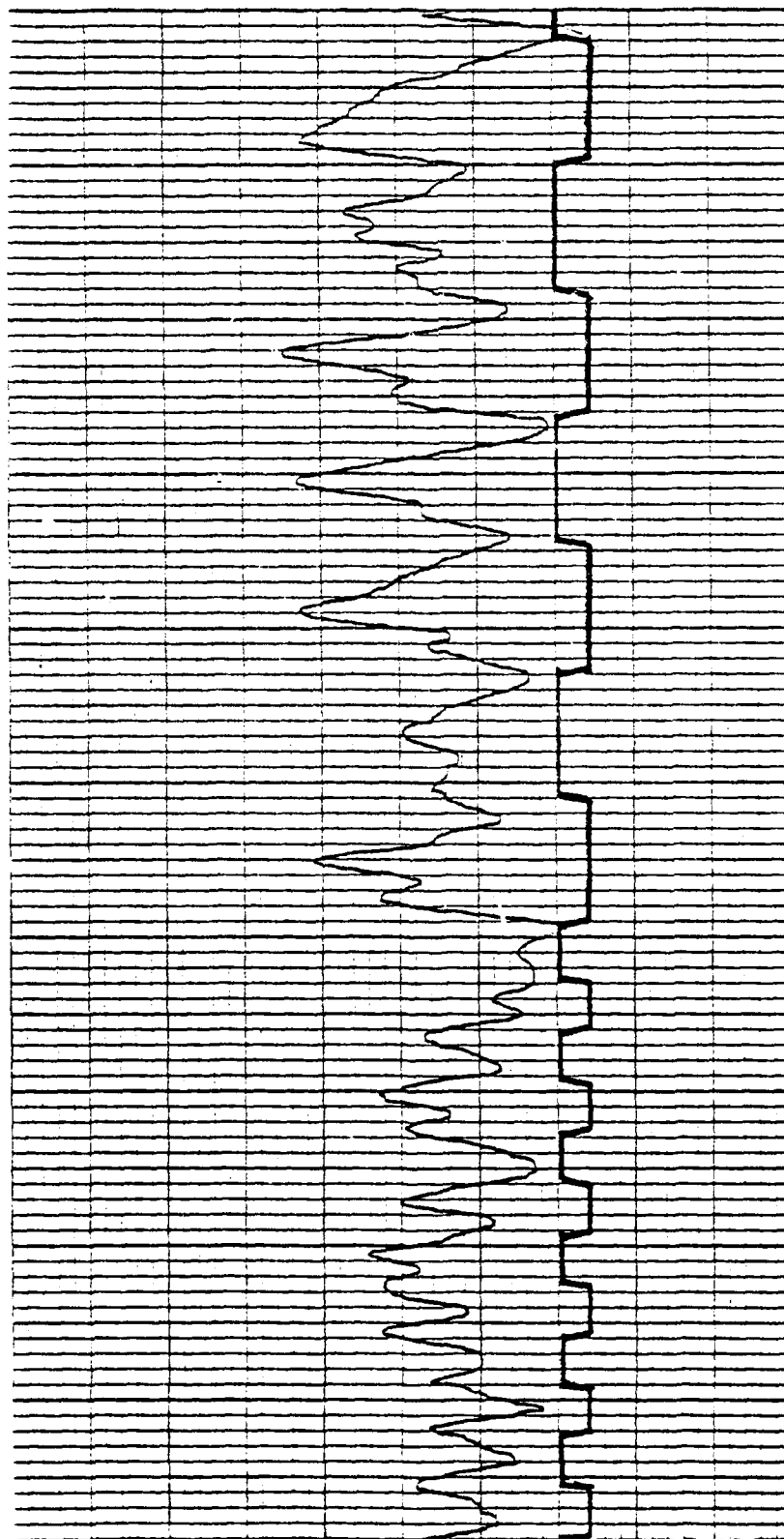
Figure 12. Average of 30 trials from the occipital channel of subject 3. The stimulating frequency changed from 15.0 alternations/sec. to 6.0 alternations/sec. as shown in the pulse channel (lower trace). The duration of the traces is 2 seconds.
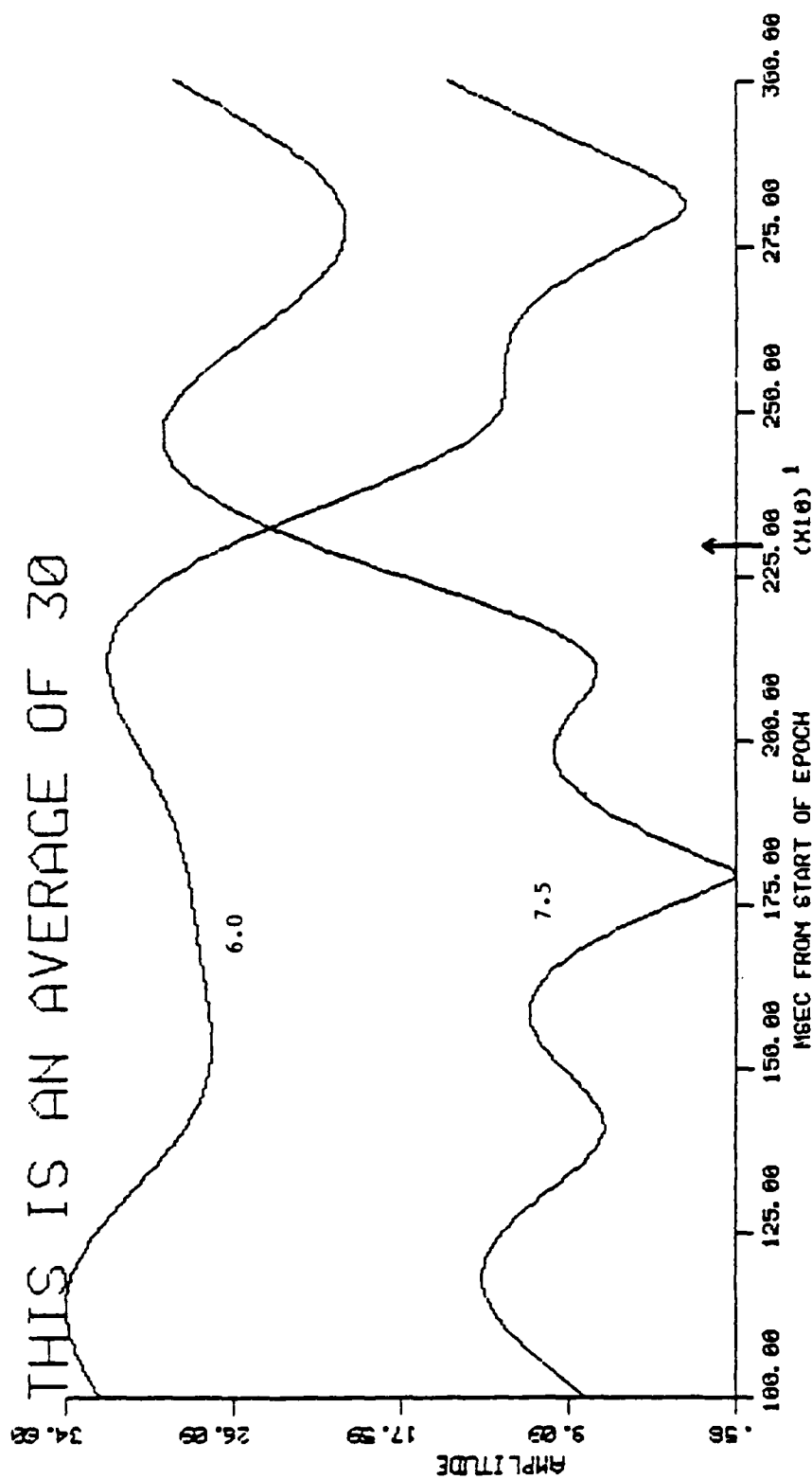
Figure 13. Complex Demodulation output of the average of 30 epochs for the transition from 6.0 Hz to 7.5 Hz. This represents 2 passes of the demodulation algorithm with center frequencies at 6.0 Hz and at 7.5 Hz. The period shown is the middle 2 seconds of a 4 sec. epoch to eliminate filter warm-up and cool-down effects.

68

O: S#1 6.0 - 10.0 HZ.
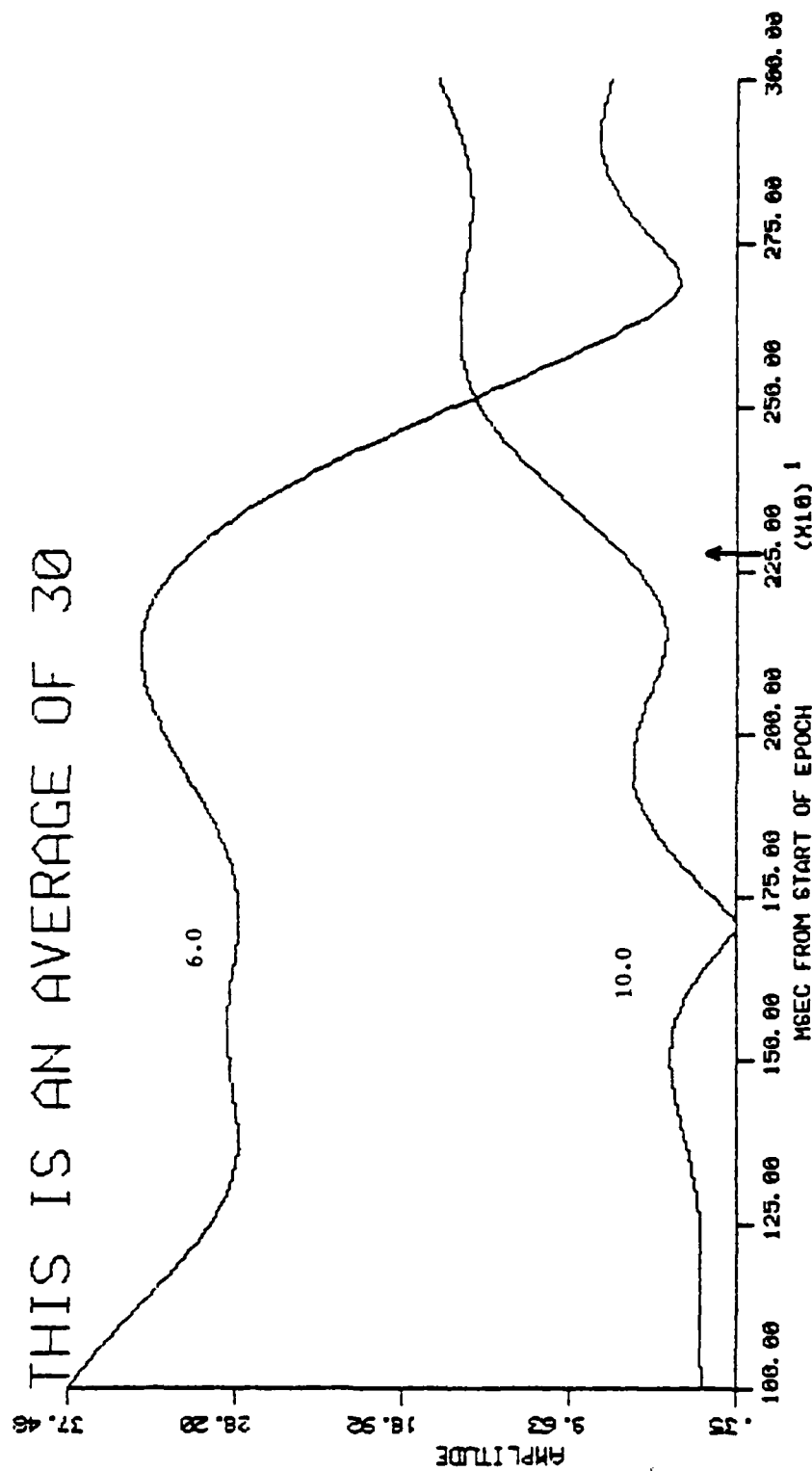
Ø1   TXABR   AMPLITUDE

THIS IS AN AVERAGE OF 30

Figure 14. Complex Demodulation output of the average of 30 epochs for the transition from 6.0 Hz to 10.0 Hz. This represents 2 passes of the demodulation algorithm with center frequencies at 6.0 Hz and at 10.0 Hz. The period shown is the middle 2 seconds of a 4 sec. epoch to eliminate filter warm-up and cool-down effects.

Figure 15. Complex Demodulation output of the average of 30 epochs for the transition from 6.0 Hz to 15.0 Hz. This represents 2 passes of the demodulation algorithm with center frequencies at 6.0 Hz and at 15.0 Hz. The period shown is the middle 2 seconds of a 4 sec. epoch to eliminate filter warm-up and cool-down effects.
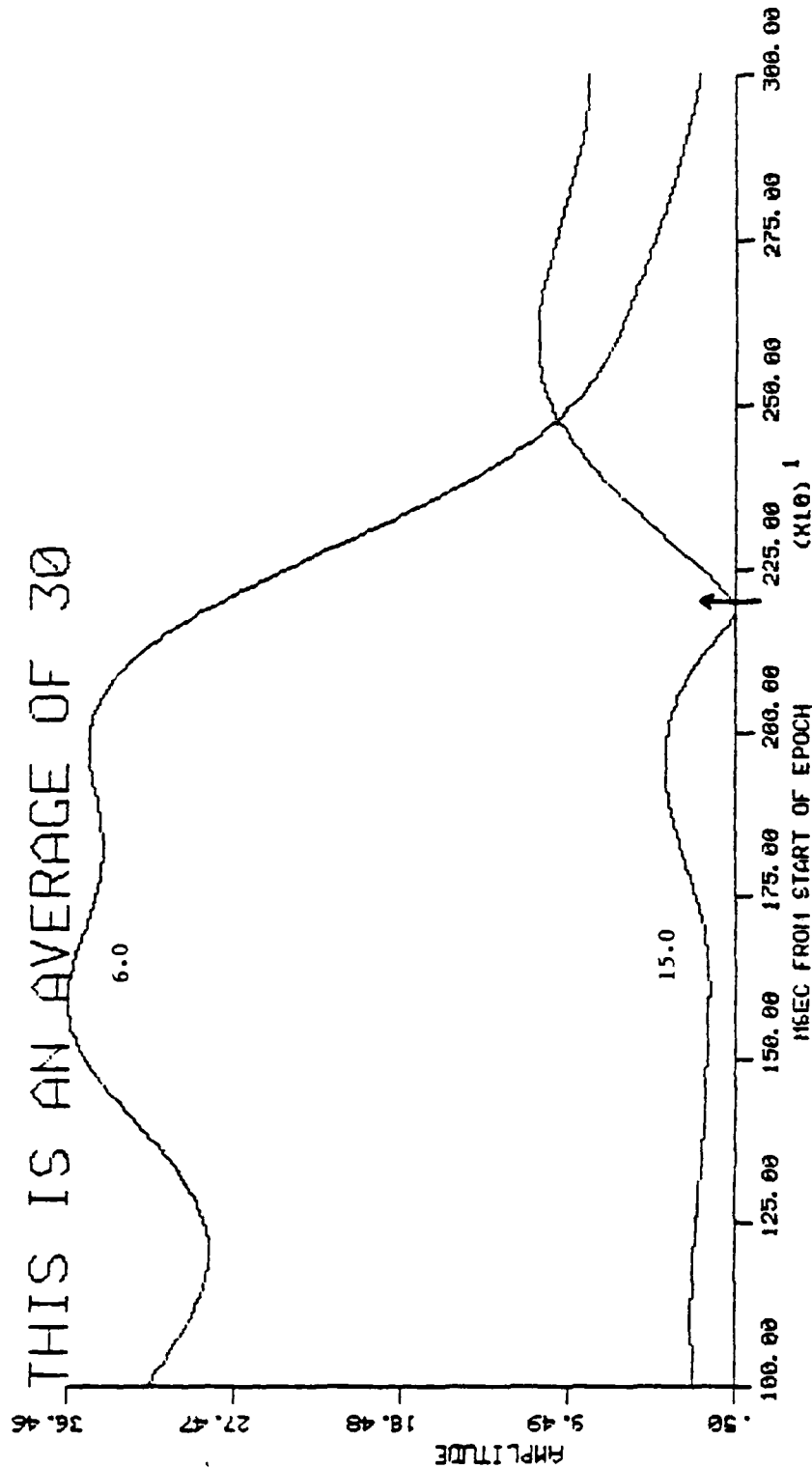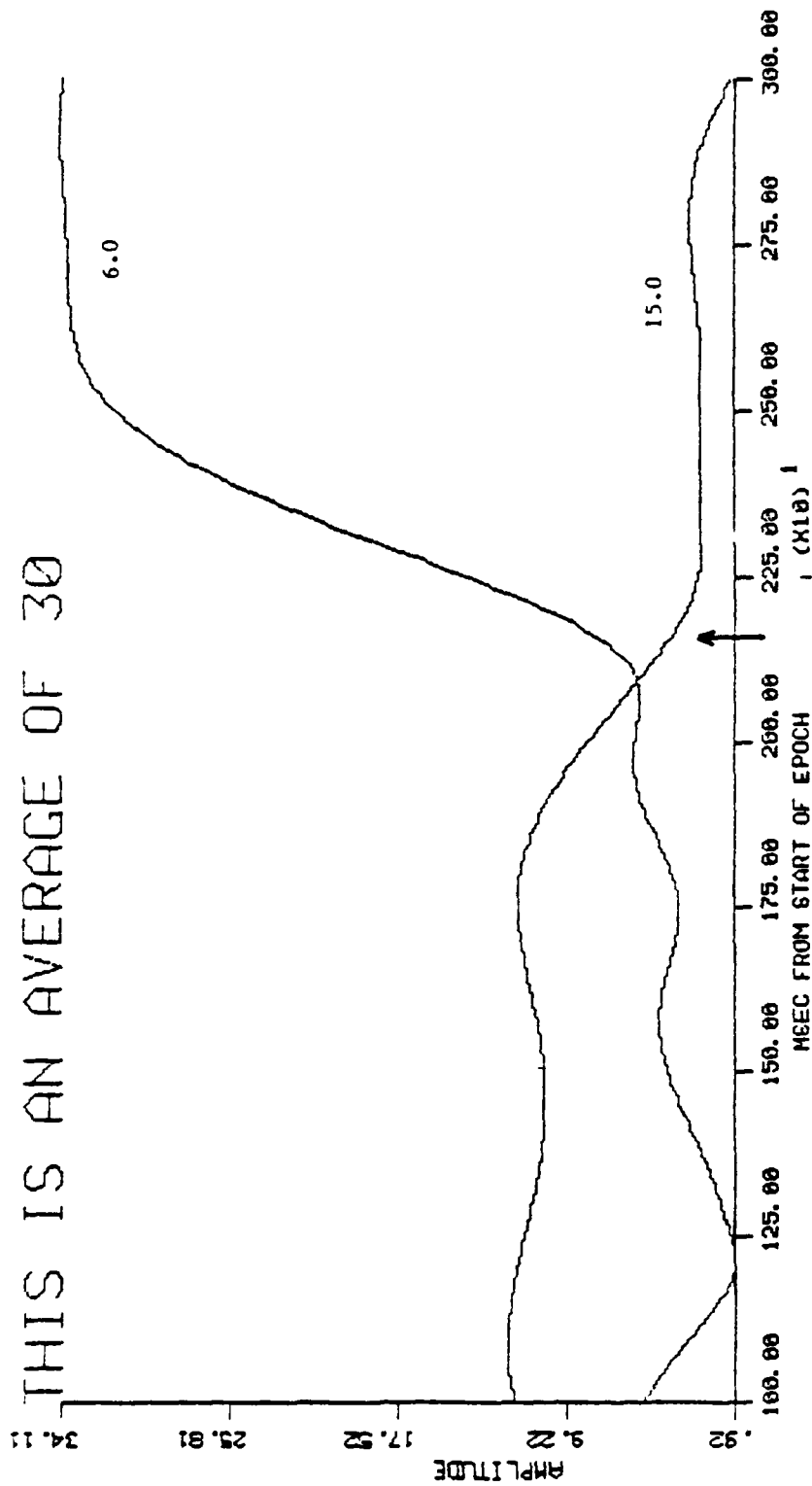
Figure 16. Complex Demodulation output of the average of 30 epochs for the transition from 15.0 Hz to 6.0 Hz. This represents 2 passes of the demodulation algorithm with center frequencies at 15.0 Hz and at 6.0 Hz. The period shown is the middle 2 seconds of a 4 sec. epoch to eliminate filter warm-up and cool-down effects.

The times from actual transition to maximum slope of the frequency which stopped and from transition to maximum slope of the frequency which started are shown in Table 6. As explained earlier, the complex demodulation algorithm "looked ahead" to the end of the data sample before computing its output. Since it "reads the future", the output predicts comeing events and begins to show the transition before it actually occurs. This property leads to the seemingly paradoxical situation in Table 6 where the maximum slope of the starting frequency sometimes occurs before the frequency actually began. Phase output of the complex demodulation has been suggested to be the best measure of arrival of a wave process (Childers, 1973). As described earlier, in application to these EEG data, phase changes could not be uniquely identified to estimate the arrival or departure of each frequency. If the complex demodulation is performed on the sine wave output of the stimulus generator, estimates of the arrival and departure of each stimulus frequency can be obtained. Using the maximum slope of these outputs as estimates of the arrival and departure of each stimulus frequency eliminates negative numbers seen in Table 6, but does not change the relationships between transition conditions.

Table 6

Mean time in msec. between 1) the time from stimulus
transition to maximum slope of the stopping frequency, and
2) the mean time from stimulus transition to maximum slope
of the starting frequency.

FREQUENCY	TIME TO STOP	TIME TO START
6.0 - 7.5	7.02	-5.15
6.0 -10.0	15.13	2.31
6.0 -15.0	13.11	-2.07
10.0-15.0	12.91	-5.07
7.5 - 6.0	4.87	-9.13
10.0- 6.0	1.95	1.20
15.0- 6.0	14.32	2.36
15.0-10.0	12.93	0.56

Neither comparison of all transition conditions
together (ANOVA) or in pairs (T-test and nonparametric
statistics) revealed any differences at or beyond $p < .05$ for
any computed measure. This was true for fundamental
frequencies as well as their harmonics. Slower frequencies
produced higher amplitude activity than faster ones.

The mean time between starting and stopping frequency
(Starting - Stopping = Time Between) for each frequency is
shown in Table 7. A negative value means the maximum slope
of the stopping frequency occurred after the maximum slope

of the starting frequency. The differences between the highest frequencies (10.0 and 15.0 Hz) were larger than differences between any other pairs studied, but was nonsignificant. There was a trend for the time between maximum slope of the ending and beginning frequencies to be shorter when a faster frequency changed to a slower one (e.g. 10.0 Hz to 6.0 Hz) than when a slower frequency changed to a faster one (e.g. 6.0 Hz to 10.0 Hz), but this was not true for all subjects and all pairs of frequencies.

Table 7

Mean time in msec. between maximum slopes of the starting frequency and stopping frequency for each frequency pair.

Frequency	Mean (Fundamental)	Mean (Harmonic)
6.0 - 7.5	12.17	-10.10
6.0 - 10.0	12.82	0.83
6.0 - 15.0	15.19	-4.00
10.0 - 15.0	17.98	27.25
7.5 - 6.0	-10.10	-6.50
10.0 - 6.0	0.83	2.33
15.0 - 6.0	-4.00	-24.00
15.0 - 10.0	27.25	23.50

It is clear from these experiments that the brain can rapidly follow a discretely changing temporal stimulus. It also seems plausible that the brain's ability to make such changes must be affected by a large number of variables such as the input frequency and perhaps sensory and cognitive factors. The inability to find statistically reliable temporal differences in transitions between various frequencies is almost certainly due to this particular application of the Complex Demodulation. A number of improvements, discussed below, suggested themselves but were not used in this study due to time or equipment limitations.

More consistent estimates of the complex demodulate amplitude and phase functions would have been obtained if each individual epoch was demodulated and the outputs then averaged. This was not done because of the enormous time required for that analysis with the UCLA computer facility. Clearly, practical application of this analysis technique requires faster general purpose computers or hard-wired special purpose analyzers. Much faster data sampling rates may also be required, since no matter which way the final values are obtained, "jitter" caused by putting together individual epochs may be so large as to obscure small time differences related to other variables

The frequencies selected for this study may not have been optimal for identifying differences in the brain's ability to switch between them. It is well known that there are frequency windows in which steady-state activity is differentially sensitive to various sensory factors. Some of these windows extend as high as 45-56 Hz (Regan, 1972; Wilson, 1980). Further exploration with higher frequencies than used here may be fruitful.

The 30 epochs used for each average here represents a minimal number to produce visually identifiable steady-state responses. This relatively small number of trials was used to attempt identification of steady-state changes within as short a time as possible to maximize the usefulness of this approach in operational settings where data often must be collected quickly. Averaging together a larger number of epochs (eg.,100) might improve the complex demodulation estimates.

The experience of collecting this data convinced the investigator that the brain's ability to follow changing frequencies can be measured and may be related to stimulus or other factors. This conviction led to application of the same paradigm to an experiment which manipulated subject fatigue.

Experiment II

76

Four subjects (2 male and 2 female) performed a Jex critical instability tracking task for 4 hours. One subject (female) did not produce identifiable steady-state and was not included in the analysis. No reason could be found why this subject did not produce clear steady-state responses. This subject performed the tracking task as well as the others and has no history of neurological or visual difficulties.

In the Jex task, an electronically unstable element is tracked. As tracking error builds up, it is fed back into the system so subjects are actually tracking their own error. If there is no error, the unstability of the system quickly begins to create new errors.

Temporal frequency following (TFF) testing was performed at the end of each half hour for a total of 8 TFF sessions for each subject. The subjects tracked for 20 minutes, were TFF tested, rested for 5 minutes, then began tracking again. There was a 10 minute break after the fourth testing session (2 hours into the task).

TFF testing consisted of 60 alternations between 6.0 Hz and 15.0 Hz (30 changes from 6.0 to 15.0 Hz and 30 changes from 15.0 to 6.0 Hz). EEG recording and TFF apparatus and procedures were the same as in Experiment I. As discussed in Experiment I, vertex failed to produce easily identifiable steady-state and the results are reported only for occipital

77

EEG.

Results

Subjects were reluctant to say that they were fatigued
by this task. Irritation and boredom were the most common
feelings reported by all subjects. The experimenter reported
that 2 subjects seemed very tired after the task, but the
other 2 (including the one who did not produce clear
steady-state) did not. There was no large tracking
performance decrement over time.

Complex demodulation of the data produced highly
variable estimates of amplitudes and measures derived from
maximum slopes that were similar to those found in the
previous experiment. Table 8 shows the mean time from
transition to maximum slope of the stopping frequency and
the starting frequency, as well as the time between maximum
slopes of starting and stopping frequencies. There were no
statistical differences for fundamental or harmonic
frequency measures correlated with fatigue, although there
was a trend for the fundamental frequency amplitude to get
smaller with increasing time in the task.

Table 8

Mean time in msec from transition to 1) maximum slope of stopping frequency and 2) maximum slope of starting frequency. Also shown is the difference between time to stopping frequency and time to starting frequency.

TESTING SESSION	STOP FREQ (6.0)	START FREQ (15.0)	DIFFERENCE	STOP FREQ (15.0)	START FREQ (6.0)	DIFFERENCE
1	219.9	231.7	-11.8	238.7	231.5	11.7
2	220.6	227.6	-7.0	209.3	224.2	-10.2
3	219.3	236.0	-16.7	214.0	221.4	-8.8
4	225.5	227.9	-2.4	223.8	240.3	-8.4
5	225.1	216.0	9.1	224.8	238.0	-9.2
6	225.9	231.0	-5.1	228.8	262.6	-33.8
7	236.1	219.5	16.6	241.5	219.9	21.6
8	226.2	226.1	0.1	220.7	235.3	-14.6

In order to explore this amplitude difference further, two consecutive one second epochs (EPOCH 1 and EPOCH 2) just before each transition were spectrally analyzed. Spectral values for 6.0 and 15.0 Hz and their harmonics, as well as control frequencies (8.0 and 17.0 Hz), were evaluated by the ANOVA.

Separate ANOVASs were performed for each frequency of interest. ANOVA main variables were epoch 1 vs epoch 2 (Epoch) and testing session (Fatigue - 8 sessions). None of the control frequencies (8.0 and 17.0 Hz) showed any differences or trends as a function of Fatigue or Epoch. Figure 17 shows the mean spectral values for 6.0 Hz and 15.0 Hz, averaged over EPOCH, when the steady state frequency was 6.0 Hz and 15.0 Hz, as a function of time in task.

As observed in the complex demodulation, amplitudes of 6.0 Hz activity when the steady state stimulus was 6.0 Hz was higher than for 15.0 Hz when the steady state stimulus was 15.0 Hz. There was no differences between 6.0 and 15.0 Hz when the steady state was not at their frequency.

For 6.0 Hz, when 6.0 Hz was the steady state stimulus, there was no difference between the two epochs and no significant change over time (Fatigue), although the overall decrease seen in Figure 17 approached significance at $p<.05$ ($F=2.22$; $df=7,14$; $p<.10$ - F at $p<.05=2.78$). There is a clear decrease over the first 4 time periods then

80

considerable variability through period 8.

For 15.0 Hz, when 15.0 Hz was the steady state
stimulus, there was a difference between epochs (F=3.03;
df=7,14; p<.05) and a statistically clear decrease in
amplitude over testing session (F=3.77; df=7,14; p<.025).

When the steady state at each frequency is present,
there is a general reduction in amplitude from testing
session 1 to 4, an increase in session 5 (which followed the
10 minute break), a decrease in session 6 and a continued
decrease for 15 Hz with an increase for 6.0 Hz through
session 7, and an increase for both at session 8. None of
these changes are observed in the spectral amplitudes of
these frequencies when their steady-state stimulus is not
present. In addition, no changes were observed in control
frequencies of 8.0 and 17.0 Hz, eliminating the possibility
of an overall reduction in EEG activity as a function of
fatigue.

Analyses using percent spectra instead of raw values
and comparing the first 10 trials with the last 10 trials of
each session did not reveal additional significant
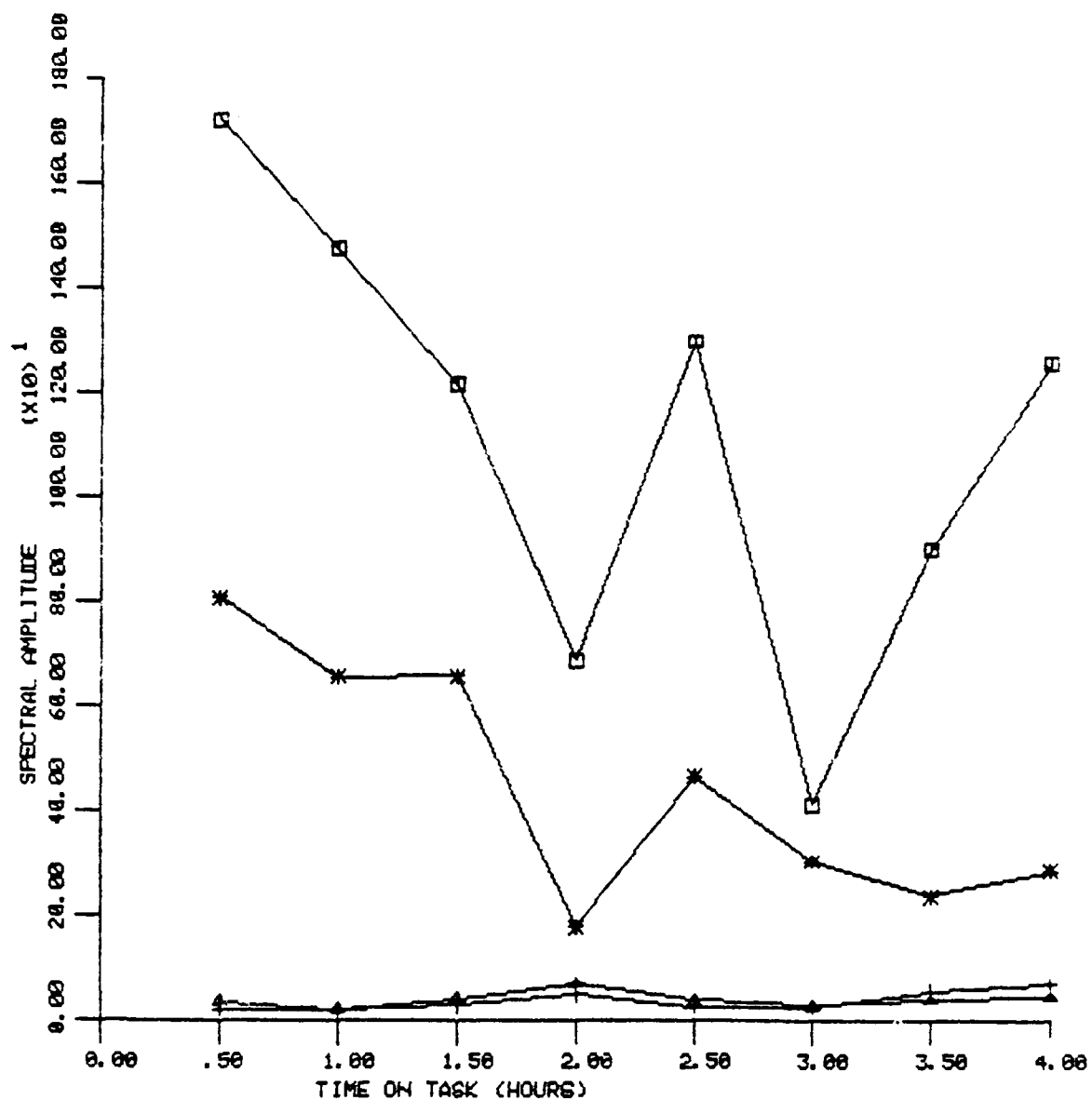differences.

Figure 17. Mean spectral amplitudes (arbitrary units) over time on task.

□ = 6.0 Hz spectra when the steady-state frequency was 6.0 Hz.

△ = 6.0 Hz spectra when the steady-state frequency was 15.0 Hz.

+ = 15.0 Hz spectra when the steady-state frequency was 6.0 Hz.

* = 15.0 Hz spectra when the steady-state frequency was 15.0 Hz.

Discussion

Complex demodulation of temporal frequency following
between 6.0 Hz and 15.0 Hz did not reveal statistically
reliable effects correlated with continued performance over
4 hours in a Jex critical instability tracking task.
Amplitude of the demodulated output suggested that there
were differences over testing sessions. Spectral analysis
of ten 1 second epochs immediately before frequency changes
verified that there were differences in the amplitude of the
driven frequency over testing sessions. This difference was
statistically verified for 15.0 Hz. This is the first
demonstration of a change in steady-state amplitude
correlated with fatigue and also represents one of the first
correlations of steady-state amplitude with a psychological
variable.

Most research with the steady-state ER has been
confined to the physical stimulus parameters which generate
and affect steady-state amplitude and phase relationships.
Some clinical applications to evaluate the integrity of the
visual system have also been described (Regan, 1972).

In his review of the contribution of
psychophysiological techniques to aircraft design and other
operational problems, O'Donnell (1979) discussed the

83

implications of steady-state determination of visual parameters. In his view, this technique (as well as the transient ER) is important because of its apparent ability to provide information about the visual system without requiring subjective reports. This should contribute to reducing much of the variability typically found in psychophysiological studies and allow the use of unselected, non-ideal subjects which are frequently of more interest to the human engineer than the idealized subject. Equally important is the potential contribution of this ER as an independent measure of fatigue or psychological variables.

The attempt to correlate temporal changes in EEG activity with stimulation frequency and fatigue was not statistically successful. However, this is the first time brain processes at the moment of temporal change have been investigated in detail and it is expected that with the proper analytical tools or experimental procedures, the time course of EEG following will be found to correlate with stimulus, sensory, and/or other factors.

The visual evoked response is sensitive to a number of stimulus factors which affect sensory input. These include sharpness (focus) of the stimulus (Harter and White, 1968), number of contrast borders (Spehlmann, 1965), intensity of the stimulus (Shipley, Jones, and Fry, 1966), and the spatial frequency of the stimulus field (Campbell and Maffei, 1970). From the information processing viewpoint, the timing of these components coincides with the "encoding" portion of the processing sequence (Norman, 1969).

VER components between 200 and 500 milliseconds after stimulus presentation appear to reflect cognitive factors. A large positive peak at approximately 300 milliseconds (P3 or P300) is extremely sensitive to parameters which affect information processing. Significant differences in the amplitude of this component have been found in the ER from different modalities as a function of selective attention (Wilkinson and Lee, 1972), stimulus probability (Sutton, 1969), relevance or significance of the stimulus (Ritter and Vaughan, 1969), and physical detectability of the stimulus (Hillyard, Squires, Bauer, and Lindsay, 1972). In the Sternberg paradigm, the VER has been shown to reflect memory load (number of items in the memorized set) and meaningfulness (Gomer, Spicuzza, and O'Donnell, 1976).

Sternberg (1969a, b; 1975) has suggested that several cognitive processing steps can be evaluated from response times (RTs) obtained in his memory search task. In addition, it is convenient to manipulate a number of cognitive processing variables with this task. In the typical "fixed set" methodology, the subject is required to memorize a set of items, usually letters of the alphabet. These memorized items constitute the positive set, and all other items constitute the negative set. Once the positive set has been memorized, the subject is shown a "probe" item (a letter of the alphabet). The subject's task is to determine whether the probe item is a member of the positive set or a member of the negative set. A differential response is then required. Reaction time is calculated for the positive and negative sets separately and these are plotted as a function of a number of letters in the positive set. For most types of memory items this plot is linear, and a simple linear regression equation can be derived for the data.

Sternberg has suggested that the intercept of the regression equation represents the time involved in scanning and retrieving information from memory so that a decision may be made whether the probe item belongs to the positive or negative set. Sternberg has proposed that these processes are measured independently with this paradigm, and that they can be independently affected by variations in processing requirements imposed by the stimulus. The methodology therefore provides an ideal vehicle for assessing cognitive

or information processing components as differentiated from sensory and motor components.

Because the VER is sensitive to stimulus focus, number of items in a memory set, and the meaningfulness of stimuli, when each are tested individually, the present experiment investigated the ability of the VER to be selectively sensitive to each of these factors presented together. The effects of manipulating memory set and meaningfulness has sometimes been used as an index of workload. A single measure which could differentially identify sensory and cognitive factors as they contribute to workload and performance would be a useful tool for evaluation of human engineering and performance design factors.

Due to difficulties with data recording unrelated to the design or outcome, this experiment has been run in its entirety 3 times. The results presented here are still not complete since most of the EEG data is contaminated and cannot be analyzed. Due to the strong interest in these results by the Neuropsychological Laboratory at AMRL, the experiment will be rerun one more time by this Laboratory early in 1980.

Apparatus and Procedures

Each replication of this experiment has used 4-5

87

subjects. The last replication, reported here, used 5 subjects (1 female and 4 males) between the ages of 20 and 40 years. Subjects were comfortably seated in a dark, soundproof chamber. They were approximately 60 cm from a circular display field 3.15 degrees in diameter, which was centered in the rectangular opening of a T-scope field which was 5.73 X 2.50 degrees.

Electrodes were placed on the scalp of each subject at the vertex (Cz) referred to right mastoid and on the midline occiput (Oz) referred to right mastoid (left mastoid ground). At the start of each test day, a circular patch of the scalp, approximately 1 cm in diameter, was abraded at the electrode sites to insure that the measured impedance between electrodes did not exceed 1.5 Kohms. EEG was recorded on FM tape and input to the Nicolet signal averager to provide time-locked averages from each experimental condition.

Subjects memorized 1, 4, or 8 letters of the alphabet (the positive set) for each of 3 memory load experimental conditions. These are referred to as M-set 1, M-set 4 and M-set 8. A control condition in which no items were memorized and no differential response was required is referred to as M-set 0. In this control, subjects were instructed to make a response to the right-hand key (all subjects were right-handed) as fast as possible after the stimulus was presented. All stimulus letters were presented for 1 second through a tachistoscope. On any given trial,

the subject was required to respond to the stimulus letter as positive (one of the items memorized) or negative (not memorized) by pressing the appropriate response key located under the index finger of each hand. Letters from the positive set appeared on 50% of the trials in a randomized sequence. Three subjects pressed the right-hand key for a positive response, the other two pressed the left-hand key for a positive response.

On each trial the stimulus letter was presented at one of 3 focus levels. Focus changes were obtained by adjusting the fine lens focus on the slide projector used to present stimuli. Focus level 1 corresponded to the stimulus in sharp focus, level 3 to maximum defocus (focus adjustment rotated as far as possible) and level 2 as half way between 1 and 3 (focus adjustment rotated half way between 1 and 3). No spatial frequency measures of focus were taken in these pilot studies. Figure 18 is a drawing of a stimulus letter under the 3 focus conditions. The drawing is not a high fidelity representation of the stimulus as seen by the subjects, but is included to give an idea of the various focus levels. Letters from positive and negative sets appeared equally often under all focus levels.

Figure 18 Drawing of a typical stimulus letter under the 3 levels of focus used in the Sternberg Focus experiment.

Each M-set required a single testing session. Each session consisted of positive and negative items presented at 3 focus levels for a total of 6 conditions. Each condition was presented 32 times for a total of 192 trials per session. Each session took about an hour to complete. M-sets were tested on different days and each subject was in the lab on 4 separate days to complete the experiment.

Results

I. Behavioral Data

A. Percent Correct Responses

In spite of severe blurring of the stimuli in focus level 3, subjects identified positive vs negative set letters very well. Table 9 shows the percentage correct identifications for each M-set/focus level combination. M-set 0 (control) does not appear as no choice responses were required in that condition.
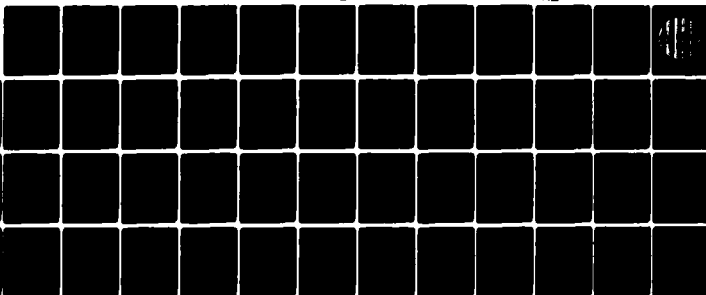
Table 9

Percent correct responses at each M-set and focus level.

Focus

Mset	1	2	3	Mean
1	95.3	95.0	94.7	95.0
4	91.1	91.3	89.6	90.7
8	89.4	89.5	84.9	87.9
Mean	91.9	92.0	89.7	91.2

Focus levels 1 and 2 produced very similar performance with correct responding down somewhat for focus level 3. Much larger deficits are seen with increasing M-set.

The analysis of variance applied to the data of Table 9 revealed a significant reduction in percent correct performance with increasing M-set ($F = 4.835$, $df = 2,8$, $p < .05$). T-test comparisons showed a significant difference between M-set 1 and M-set 8 ($t = 2.335$, $df = 8$, $p < .05$). M-set comparisons 1 vs 4 and 4 vs 8 were not significantly different. No statistical differences were found due to focus level, positive/negative stimuli, or any interactions.

9. Reaction Time (RT)

The reaction times for subject 5 were considerably longer than the other subjects. Therefore, a logarithmic transform was applied to all data before performing the analysis of variance (Meyers, 1966). The analysis included main effects for M-set, positive/negative stimuli (set), and focus.

As typically found in the Sternberg task, RTs were longer to negative set than positive set items. This effect approached significance by the ANOVA (F = 6.823; df = 1, 4; F at p<.05 = 7.71). Every subject showed a difference in this direction, which was significant by the nonparametric Sign test (N = 5, p = .035).

The expected increase in reaction time over M-set was significant (F = 4.685; df = 2, 8; p<.05) as was an increase in latency with decreasing focus (F = 13.403, df = 2, 8; p<.01). The interaction between these conditions was also significant (F = 10.365, df = 4, 16; p<.001) and suggests that focus modified the way latencies increased over M-sets.

Figure 19 shows the mean latencies over M-set for each focus level. The regression lines computed by the linear least squares fit are also drawn. This figure shows that for focus level 3 there is apparently a considerable deviation from linearity (uncertainty of the linear fit is 3.74) while the other focus levels seem well fit by a straight line (uncertainty of 1.42 for focus 1 and 0.77 for focus 2).

93

Response latencies in the control condition were 256 msec for focus = 1, 252 msec for focus = 2, and 254 msec for focus = 3. Differences between these values did not approach significance. The overall mean RT for the control was 254 msec.

II. Evoked Potentials

Due to difficulties with the data collection procedures and equipment, all of the occipital and most of the vertex EEG data were lost for all subjects. Only the vertex channel for one subject was salvaged and this is not sufficient data to justify an analysis here. As this experiment is being rerun at the Neuropsychological Laboratory at AMRL, a full data analysis will appear in a Technical Report if the results warrant.
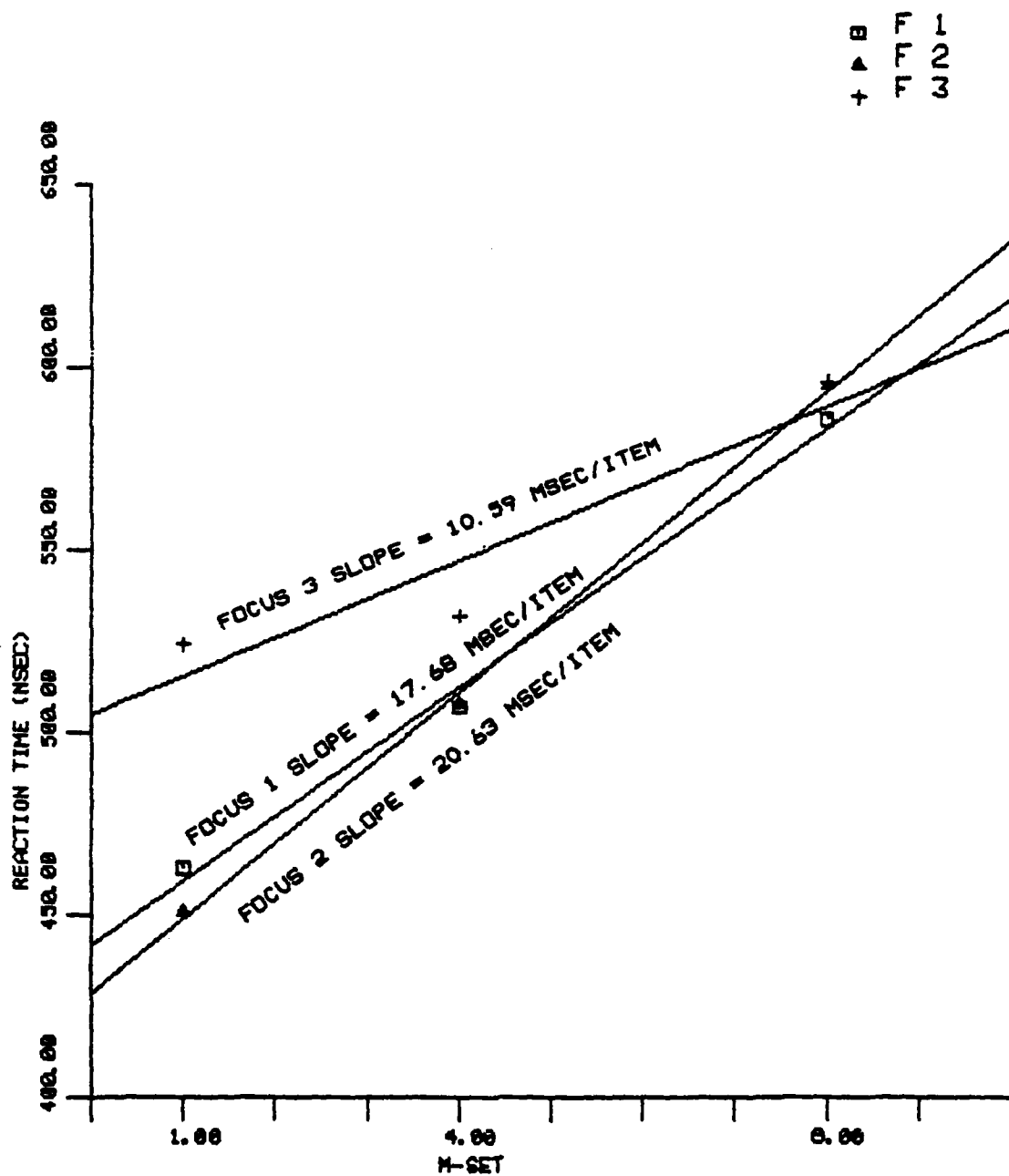
Figure 19. Mean reaction time and regression lines over M-set for each focus level. F1 = focus level 1, F2 = focus level 2, F3 = focus level 3.

The integrity of the visual stimulus (focus) profoundly
affects response RT in the Sternberg memory load task.
Correct performance was not significantly affected by focus
but was affected by M-set, indicating that memory load is a
more important factor determining correct responding than
stimulus integrity in this situation. These differences
were small as subjects performed with a high level of
accuracy in spite of stimulus defocusing.

As expected in the Sternberg task, RT increased with
M-set. Increased blurring (focus level) also increased RT.
The interaction between these factors seems primarily due to
a strong nonlinear performance function over M-set at focus
level 3. Surprisingly, the primary effect of focus seems to
be at M-set 1 or 4 rather than at 8. It may be that for
M-set 8, memory load is the limiting factor on performance
and is less influenced by focus.

Sternberg (1969a, b) has developed a theory to account
for RT data graphed in the manner of Figure 20. He contends
that the Y intercept represents: a) the time required to
encode or preprocess the test stimulus into suitable form
for content evaluation and b) the time needed to organize
and execute the motor response. The slope, on the other

96

hand, reflects the time per unit item involved in scanning memory and retrieving information for comparator processing.

The slope of the best fit regression line is somewhat steeper for focus level 1 and 2 than that reported by Gomer, Spicuzza, and O'Donnell (1976). This difference may be due to the relative inexperience of subjects in this experiment, compared to theirs, resulting in increased processing time per item. The slope for focus level 3 is very small due to the non-linearity of the data.

The control condition in the present experiment is a measure of registration of the presence of a stimulus and execution of a motor response. Because no differential response was required, some set-up time required to select the appropriate motor pathway for response is undoubtedly not measured. Control latencies were not affected by focus and the overall average of 254 msec is a crude measure of the basic recognition and motor activation sequence. The difference between the control level and the intercept of the regression lines should be a clearer measure of the cognitive activities required to identify the stimulus and set up the choice motor response. Interestingly, the intercept for focus level 2 is slightly lower than for focus level 1, indicating a similar or slightly lower preprocessing time with a larger (slope) amount of time spent searching for each item.

97

While ER analysis is not possible here, the literature prompts some speculation on what may be expected when the ER data is available. Early ER components were examined by Harter and White (1969) who reported that a defocused checkerboard pattern reduced the size of the visual evoked response peak at 100 msec. after stimulus presentation. The P3 peak has also been shown to vary with detectability of a stimulus (Hillyard, Squires, Bauer, and Lindsay, 1971).

Gomer, Spicuzza, and O'Donnell (1976) reported a difference in P3 amplitude as a function of M-set size. In their study, negative set amplitude decreased with increasing M-set. Ford, Roth, Dirkes, and Kopell (1973) predicted P3 latency would increase in a retrieval task as the number of memorized items to be processed increased; a prediction confirmed by Gomer, et al. From these observations it is expected that early components will reflect stimulus integrity (focus) and that P3 may be affected by the interaction of focus and memory load (M-set).

Use of the ER in operational environments has been severely limited by the necessity of providing controlled external stimuli (flashing lights or phase-shifting patterns) to produce them. The potential uses of ERs would be greatly enhanced if a naturally generated potential could by shown to contain the same kind of information as the artificially induced one. This would completely eliminate the necessity for disruption of the external visual environment to produce ERs. The possible advantage of such an ER is enormous and has immediate application in human performance environments from the aircraft to the clinic.

A number of studies have reported ERs that are apparently time-locked to such internal events as respiration and heart beat. Another naturally produced ER is thought to be generated by eye movements. These small neuronally generated potentials have been observed for some time and were originally thought to be due to muscle artifacts. More recently, these ERs have been recognized as central nevrous system correlates of voluntary eye movements (see Regan, 1972).

Very little is known about the information content of these ERs and they have been termed lambda waves (Gastaut,

99

1951; Evans, 1952a,b) with occasional reference to "corollary discharges". In some subjects, voluntary eye movements trigger such large lambda waves that they are easily observed in the raw EEG (Cobb and Pamplignioni, 1952; Evans, 1952a; Gastaut, 1951). These waves are strongly attenuated by diffuse illumination and spatially unstructured visual fields. They are absent in total darkness or when the eyes are closed. Stimulation of upper and lower retinal half fields shows differences in lambda waveforms similar to those observed in pattern presentation and pattern reversal (Jefferies, 1969).

The genesis of lambda waves is still in doubt. Some studies have suggested that lambda waves are more closely related to movement of visual stimuli across the retina rather than the movement of the eye per se (Barlow and Ciganek, 1969; Scott and Bickford, 1967). Kurtzburg and Vaughn (1972) have suggested that lambda waves are identical with ERs to pattern movement. Although Barlow and Ciganek (1969) contend that there are some minor differences in waveforms, Ebersole and Galambos (1972) have presented further evidence that lambda-like potentials from a variety of experiments are similar, do not depend solely on eye movements, and differ from potentials that do depend upon eye movements (e.g. pontine-geniculate-occipital waves of sleep and wakefulness).

Another interesting report suggests that movement in the visual field generates a positive-going potential that

100

reflects information processing. Cooper et al. (1977) found a positive-going potential which they compared to the P300 component of the cortical ER. This potential was not time-locked to eye movements or operant responses, but appeared to be generated when the observer recognized an event he had been instructed to detect.

The purpose of the present set of experiments was to determine whether or not eye movements across patterned stimuli would produce stimulus related ERs (lamda waves) that could be clearly separated from the artifacts that eye movements often introduce into EEG recording. If such ERs could be found, they would be evaluated to see if they carry information about the perceptual environment as do traditionally generated ERs.

Equipment and Procedures

The experimental design provided for a large number of parameters to be manipulated in a repetitive task in which the eyes continuously swept across a patterned field in order to maximize the opportunity for steady-state like responses to be detected by frequency analysis of the EEG.

Three subjects (2 male and 1 female) between 21 and 35 years of age were run in an exhaustive series of studies. The Ss were seated comfortably in a dark sound chamber. They

were approximately 151 cm from a circular display, 17.52 cm in diameter, subtending 6.50 degrees of visual angle. On this display was a grid, checkerboard or blank screen on which a small square (referred to as the "dot") moved from side to side. Figure 20 is a drawing of the display (bars are not to scale) indicating movement of the dot by a dotted line. The standard bars (or checkerboard) pattern had bars (or checks) 0.79 cm wide subtending a visual angle of 18.0 minutes. The subjects were instructed to keep their heads immobile and to follow the dot with their eyes only. The dot was 0.45 cm wide, subtending a visual angle of 10.2 minutes.

Electrodes were placed on the scalp of each subject at the vertex (Cz) and on the midline occiput (Oz) referred to right mastoid (left mastoid ground). At the start of each test day, a circular patch of the scalp, approximately 1 cm in diameter, was abraded at the electrode sites to insure that the measured impedance between electrodes did not exceed 1.5 Kohms. EEG and EOG data were recorded on FM tape and digitized at UCLA for frequency analysis. The Nicolet signal averager was used to provide EOG-locked averages of the EEG data (see section on facilities for a more complete description of the recording equipment). Eye movements were monitored by electrodes placed 1 cm away from the outer canthus of each eye.
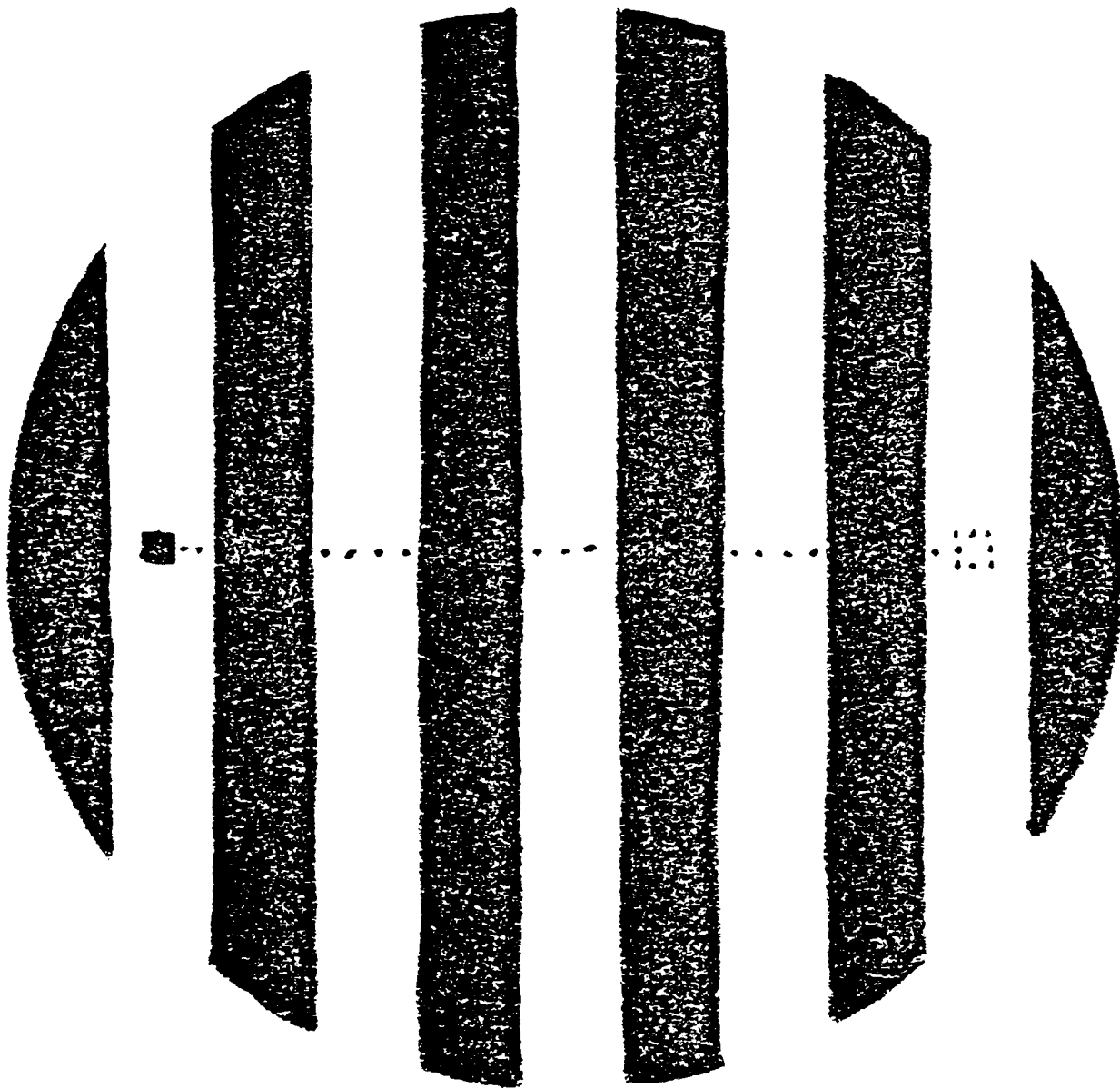
FIGURE 20 Drawing of a typical display showing vertical
bars (not to scale), the "dot", and the path of the dot.

103

The stimulus display was presented by a checkerboard generator modified to produce the moving dot as well as grid and checkerboard stimuli. This flexible device permitted a large number of stimulus parameters to be examined, as shown in Table 10. Most of these parameters were used in conjunction with each other, resulting in a total of 65 test conditions which were compared with 16 control conditions. Each condition was presented twice for each subject.

TABLE 10

Parameters examined in the EOG/ER experiments.

Frequency of dot movement

    0.5 Hz., 1.0 Hz., 1.5 Hz., 2.0 Hz.

Distance of eyemovement

    0.60 deg., 0.45 deg., 0.30 deg., 0.15 deg.

Stimulus pattern

    Standard grid, Standard grid X 2, Standard grid X 0.5,
    Checkerboard, Horizontal grid

Contrast

    Maximum, Half maximum

Control conditions

    No pattern, no dot, eyes closed

Results

The findings from all experimental conditions were
essentially the same and will be presented in more detail in
a Technical Report. For this document, a subset of these
conditions (0.5 and 1.5 Hz sweep rate; 0.14 and 0.45 degree
sweep angles; grid and checkerboard vs. blank screen
stimulus parameters) will be discussed.

Subject Reports

After each data collecting session, the subjects were
asked to report their subjective experiences during testing.
One subject kept a notebook with him and made notes
throughout the session.

All subjects reported difficulty remaining alert during
testing sessions. In addition, all had trouble staying
focused on the moving dot, especially at the higher
frequencies. Very soon after following began, the subjects
reported that after-images appeared on the screen. These
images included the periphery of the stimulus field, the
checkerboard (or grid) pattern, and occasionally the
stimulus dot. This was apparently a perceptual phenomenon
because the screen phosphor was extremely fast and did not
show any after-images to an observer not following the dot.

105

At frequencies of 1.5 Hz and 2.0 Hz there was often a feeling of nausea, especially with the grid pattern. The faster rates were perceived as being much more difficult to follow. All subjects claimed they were unable to successfully remain locked onto the dot at 2.0 Hz for more than a few seconds at a time. Visual inspection of the EOG showed some breaks (with excursions) while following at 1.5 and 2.0 Hz but spectral analysis revealed that all subjects followed at exactly the frequency of the dot. This was a striking example of the subjects' inability to detect their own successful performance of the task.

Associated with faster rates were reports of difficulty focusing, muscle fatigue in the neck and shoulders, and the perception that the dot stopped moving while the circular stimulus field began sliding back and forth. This last report was sometimes accompanied by the sensation that the eyes had stopped moving and the head was turning back and forth. Observation of the subjects revealed that their heads remained fixed throughout the course of the experiment. At all rates, pattern contrast seemed to fluctuate over each 30-120 second trial.

Electrophysiological Results

An example of the raw data may be seen in Figure 21. The traces in this figure (from the top) are vertex EEG, occipital EEG, EOG, and a dot stimulus driving pulse. The

106

dot stimulus driving pulse goes negative (down) when the dot reaches the left side of the screen and starts back to the right, and it goes positive (up) when the dot reaches the right side of the screen.

A. EOG

The phase angle between the EOG and dot stimulus driving pulse was obtained by taking the phase component of the cross spectrum of the two signals. As might be expected, EOG lagged behind the dot stimulus under all conditions. For all subjects, this lag increased by at least 60 percent when the frequency of following was increased from 0.5 Hz to 1.5 Hz as may be seen in Table 11A. This was consistent with the subjects' complaints of difficulty following at the faster rates. Increasing the sweep angle from 0.15 deg to 0.45 deg had little effect. Larger sweep angles increased the lag only for the grid pattern at 1.5 Hz. All subjects showed these patterns.

The presence or absence of patterned stimulus fields resulted in a less consistent picture. For at least one subject, there was a clear reduction in lag at the higher frequency when no grid was present (Grid vs. No Grid, Table 11B). This matched the subjects' comment that the dot was easier to follow on a blank screen than with a pattern.
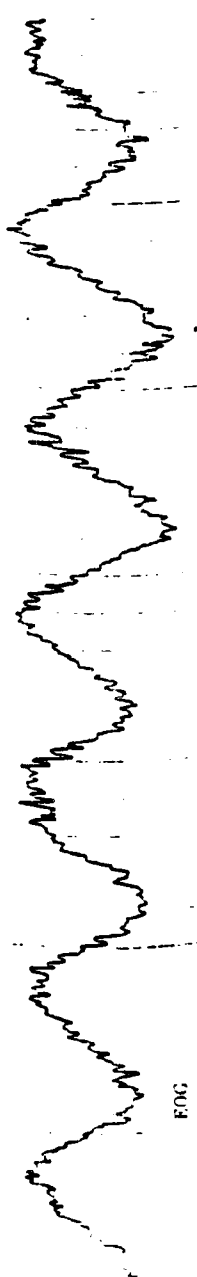
STIMULUS DRIVING PULSE

FIGURE 21 An example of raw data showing vertex EEG, occipital EEG, EOG, and the dot stimulus driving pulse.

VERTEX

OCCIPITAL

EOG

108

Table 11

EOG lag (in degrees) behind stimulus dot.

A. Grid vs Checkerboard, standard contrast. Values are the means of 3 subjects (2 repetitions each) with standard deviations in parentheses.

	Grid Frequency		Checkerboard Frequency	
Sweep angle	0.5	1.5	0.5	1.5
0.15	-66.75	-103.75	-73.00	-110.25
	(2.58)	(1.02)	(9.56)	(16.33)
0.45	-63.50	-108.50	-66.75	-110.50
	(3.04)	(1.50)	(3.96)	(3.20)

B. Grid vs no grid (blank screen) for Subject A - Values are means of 2 repetitions with standard deviations in parentheses.

	Grid Frequency		No Grid Frequency	
Sweep angle	0.5	1.5	0.5	1.5
0.15	-65.00	-104.00	-64.00	-95.00
	(1.00)	(0.00)	(2.00)	(0.00)
0.45	-60.50	-109.50	-63.50	-98.00
	(0.50)	(1.00)	(0.50)	(1.00)

B. EEG

Averages of the raw data were time-locked to the start
of each sweep of the stimulus dot from right to left. The
averaged data were difficult to read. As expected, there was
a clear component which seemed locked to the frequency of
the eye movements (e.g. dot stimulus) as may be seen in the
occipital tracing of Figure 22. This figure shows the
average of 60 epochs. The small fluctuations in the average
are at about 5.0 or 6.0 Hz. This activity does not
correspond to the frequency of eyemovements or the frequency
(or harmonic) expected from the eye crossing the stimulus
pattern. Spectral activity at 5.0-6.0 Hz was not much
higher than activity at adjoining frequencies and the source
of these fluctuations is unknown at present.

Spectral analysis was performed on 8 second epochs from
vertex and occipital leads. This produced spectral bands
with a frequency resolution of 0.125 Hz. The spectra were
examined in those bands which included the frequency of the
dot stimulus (equivalent to the EOG) as well as frequencies
expected if the eye crossing light-dark boundaries of the
patterned field were to generate potentials (Table 12).
Spectral values from these test trials were compared with
control conditions in which all parameters were the same
except that there was no patterned field.

110

Table 12

Number of light-dark boundaries crossed per second for each rate/sweep condition.

Sweep angle (degrees)	Frequency (Hz)	
	0.5	1.5
0.15	5	15
0.45	15	45

At the eye movement frequency of 1.5 Hz the occipital spectrum was considerably higher in the presence of a grid (mean = 1461, S.D. = 682) than when a blank screen was used (mean = 562, S.D. = 552). For the vertex channel, the first harmonic of the 1.5 Hz eye movement (3.0 Hz) had a much larger spectral value with no grid (mean = 412, S.D. = 271) than when the grid was present (mean = 174, S.D. = 162). None of these differences were statistically valid by parametric or nonparametric tests.
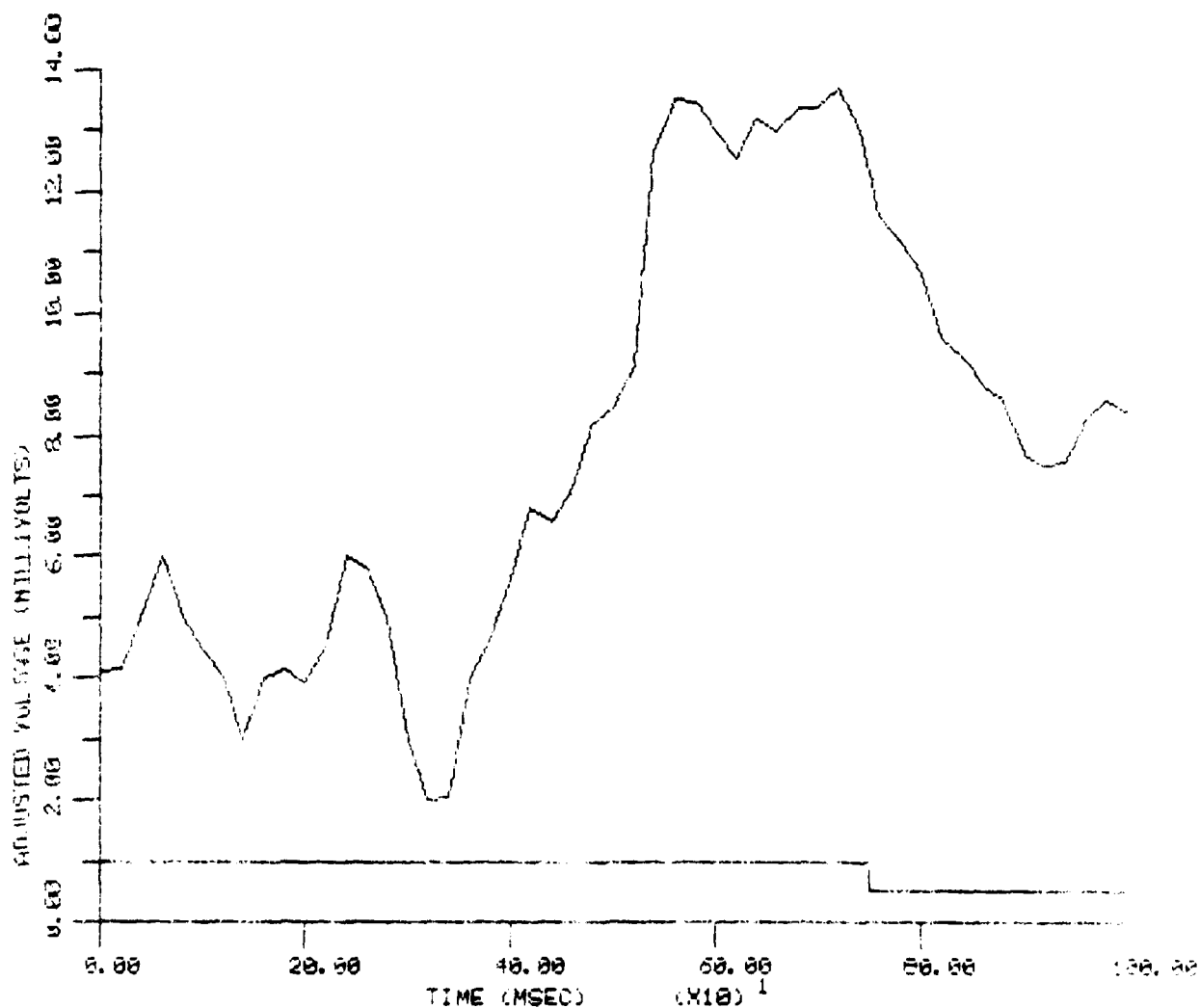
FIGURE 22. Average of 60 epochs from occipital time-locked to the start of eyemovements from right to left. The stimulus field was a checkerboard pattern. The lower trace is the dot driving pulse. Dot movements were at 1.5 Hz over a distance of 12 cm. The duration of these traces is 1 second. For this plot, all voltages have been adjusted to be above 1.0 volt.

Table 13 shows mean spectral values at the two eye movement frequencies for grid and checkerboard stimuli. Grid values are higher than checkerboard for all conditions in vertex, and at 1.5 Hz sweep frequency in occipital. At the slower 0.5 Hz, occipital showed larger spectral values for grid than checkerboard. As may be seen in this table, the standard deviations are very large when the means are large. Variances are so large that none of these differences are significant at or beyond $p < .05$.

Table 13

Mean spectral amplitudes (uv^2/Hz) of vertex and occipital EEG at the frequencies of eye movements (0.5 and 1.5 Hz). Values given are for grid and checkerboard (CKBD) stimulus patterns over 2 eye movement distances (0.5 and 0.45 degrees). Standard deviations are shown in parentheses just below the means.

		SWEEP FREQUENCY (Hz)			
		0.5		1.5	
	SWEEP ANGLE (DEGREES)	GRID	CKBD	GRID	CKBD
VERTEX	0.15	1004 (1264)	340 (104)	988 (821)	110 (49)
	0.45	698 (913)	300 (170)	552 (509)	315 (324)
OCCIPITAL	0.15	404 (368)	324 (735)	414 (369)	251 (131)
	0.45	159 (79)	549 (809)	1024 (902)	240 (54)

Table 14 shows mean spectral amplitudes of the frequencies expected if the movement of the eyes across light/dark boundaries generated brain potentials. This table is for an eye movement rate of 0.5 Hz, for grid and checkerboard stimulus patterns. In every condition, spectral values were higher for the grid stimulus than the checkerboard. Due to the very high variance of the means, no difference between grid and checkerboard was statistically significant.

Table 14

Mean spectral amplitudes (uv^2/Hz) of vertex and occipital EEG at the frequencies expected from the eyes crossing light/dark boundaries at 0.5 Hz. Values given are for grid and checkerboard (CKBD) stimulus patterns over 2 distances (0.15 and 0.45 degrees of eyemovement). Standard deviations are shown in parentheses just below each mean.

	SWEEP ANGLE (DEGREES)	FREQUENCY (Hz)			
		5.0		15.0	
		GRID	CKBD	GRID	CKBD
VERTEX	0.15	231 (249)	57 (53)	28 (11)	18 (11)
	0.45	174 (151)	63 (42)	82 (80)	20 (5)
OCCIPITAL	0.15	53 (54)	6 (4)	29 (33)	4 (1)
	0.45	63 (57)	23 (12)	34 (41)	9 (3)

Additional control experiments included removing the dot, having the subjects sweep their eyes at what they estimated to be the desired frequency, and eyes closed while moving the eyes at the estimated frequency. No statistical differences were observed for these conditions.

Discussion

The goal of identifying voluntary eye movement-generated evoked potentials that contained information about the stimulus environment was not achieved. The data, however, suggested that patterned stimuli may alter EEG responses at the primary or harmonic frequency of the gross eye movements. The inability to detect such ERs may have been due to the simplicity of the experimental design since the presence of stimulus related eye movement potentials (lamda waves) is strongly indicated by the literature. Further explorations of eye movement ERs with more complex experiments or equipment was not considered at this time since any procedures which increases the difficulty of collecting these ERs, even if they can be shown to have the desired information, reduces their usefulness in laboratory and field situations.

The subject's report that following the dot became more difficult at higher frequencies, and nearly impossible at 2

Hz, matches other reports indicating that 2 Hz is an upper limit to large, repetitive voluntary eye movements. This is supported by the finding that the EOG lagged further behind the dot stimulus at the higher frequencies. All sweep rates, especially the faster ones, were accompanied by some unusual perceptual changes. Unlike the verbal reports, the data shows that subjects do quite well following at high rates even though there are some disruptions. This suggests that human operators can make very rapid continuous eye movements for a brief time, but it is very stressful and introduces a number of unusual perceptual phenomena which could interfere with performance.

Detection in Clutter is defined here as the general problem of identifying a target(s), imbedded in a field of decoys flying toward an observer. One practical realization of this is the attempt to confuse an enemy who is trying to shoot down aircraft (the targets) by flying a group of drones in the vicinity of the real aircraft. Considerable research has been conducted on radar identification (and confusion) between targets and drones. This project was not concerned with the problem of radar (which may be jammed) but with visual identification by a ground observer.

The goals of this project included: 1) development of a methodology by which a wide range of clutter factors could be investigated in the laboratory as the first step toward identifying necessary conditions for successful visual protection or identification of target arcraft; 2) a demonstration of the usefulness of this methodology by performing an experiment to examine the effects on identification performance of the total number of targets and drones and the mixture of targets to drones; 3) evaluaion of EEG and eye movement correlates of performance to determine if there are changes in these measures which may be used to monitor or predict performance.

117

A comprehensive software package was developed for running clutter experiments on the PDP-11/35, then located in the Neuropsychology Laboratory at AMRL (Wright-Patterson Air Force Base). The hardware configuration for generating the experiment included a PDP-11/35 computer with 24K words of memory, dual disk drive, 9-track magnetic tape, VT-11 graphics terminal, and LK-40 keyboard. Behavioral responses (items identified, latency, etc.) were recorded by the computer. This system and procedures for its use are described in more detail in AFOSR 77-3184 annual report, November, 1977.

1. Pilot Studies

Three subjects were presented various target/drone pairs for 96 trials on each of 2 days. These items were selected from 3 sets of arbitrary shapes in order to determine the ability of subjects to visually detect differences in these shapes. In these studies, two objects flew a direct path to the observer starting at a distance of 5 scale miles and terminating with the subject's response indicating he detected a difference, or when the objects were 25 scale miles from the subject. These pilot experiments provided the means for evaluating identifiability of target/drone shapes and parameters such as ambient room lighting, duration of experimental session, and the like. These experiments led to the selection of delta shapes for targets and drones with only small

differences distinguishing them (Figure 23). Since the purpose of the Clutter methodology was to provide maximum flexibility for laboratory evaluation of many parameters relevant to the entire clutter, it was desirable to keep object cues at a minimum. Therefore, the objects were 2-dimensional with no perspective cues. Even with such a small difference in shape, subjects quickly became adept at identifying targets from drones.

2. Experiments

Three experiments have been run in which a) multiple targets and drones were used to vary target-drone ratio and total number of objects (EEG collected), b) one target was used with a number of drones (EEG collected), c) a partial replicaion of b) with EEG and eye movements collected. Table 15 shows all target/drone combinations for all 3 experiments. Behavioral results from all 3 experiments will be presented together. EEG results were essentially the same for all experiments and will be summarized with examples from the third experiment in which eye movement data is also available.
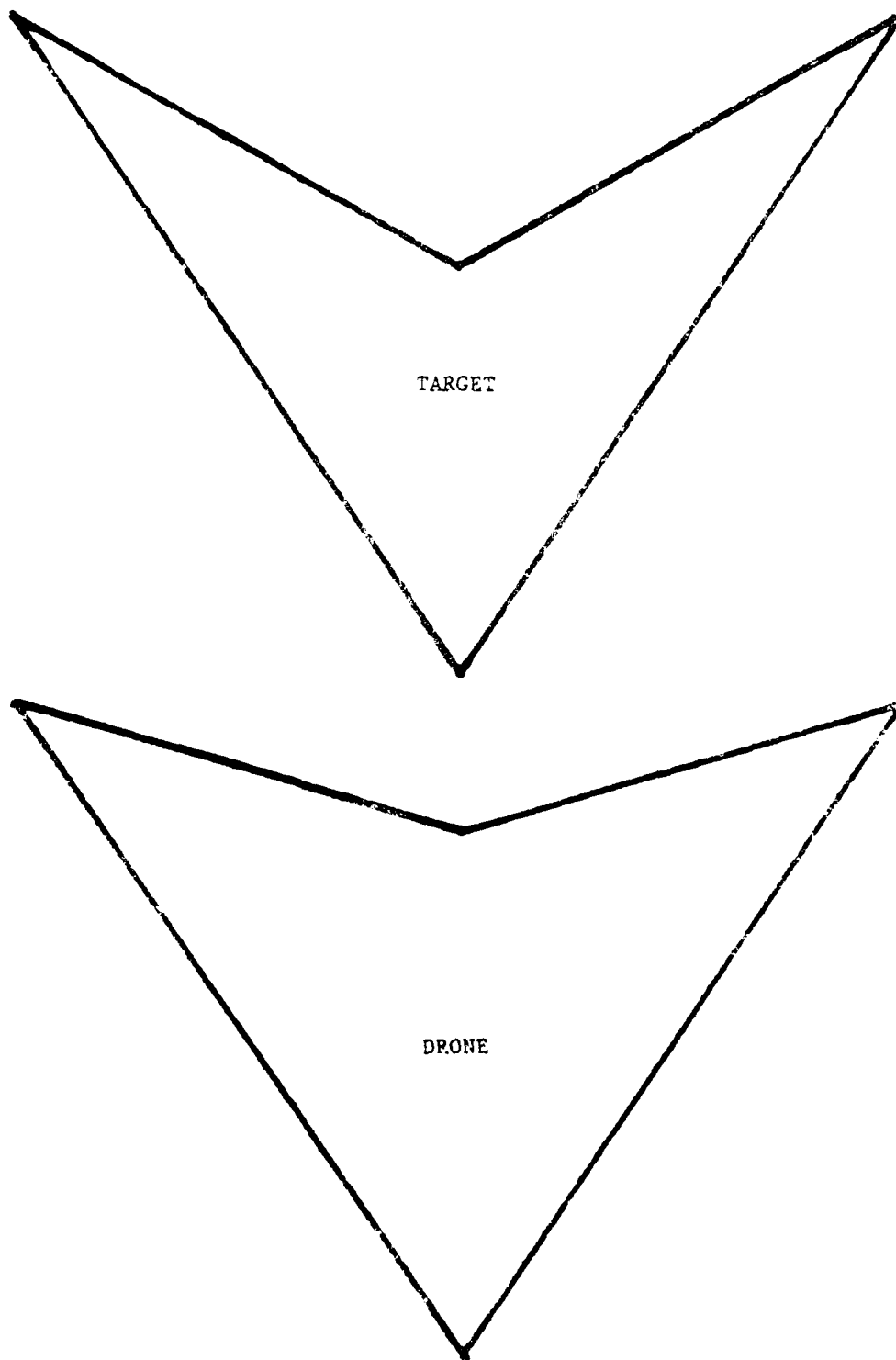
119

TARGET

DRONE

FIGURE 23. Relative size of arbitrary shapes selected for targets (top) and drones (bottom)

Table 15

	Targets	Drones	Total Items	Ratio (Targets to Drones)
Experiment I	1	1	2	1/1
	2	2	4	1/1
	3	3	6	1/1
	6	6	12	1/1
	9	9	18	1/1
	1	3	4	1/3
	2	6	8	1/3
	3	9	12	1/3
	1	5	6	1/5
	2	10	12	1/5
	3	15	18	1/5
Experiment 2	1	1	2	1/1
	1	3	4	1/3
	1	5	6	1/5
	1	7	8	1/7
	1	11	12	1/11
	1	15	16	1/15
Experiment 3	1	1	2	1/1
	3	3	6	1/1
	1	9	10	1/9

Procedures

A total of 8 subjects have participated in these experiments. Four were male flight-line pilots between 22 and 30 years of age (experiments 1 and 2). The remaining four were 2 males and 2 females between 20 and 40 years of age (experiment 3).

Subjects sat in a darkened cloth enclosure with their

eyes approximately 60 cm from the graphics screen. The graphics screen presented a viewing area of 22.86 cm high by 27.94 cm wide. The keyboard for responses was located so subjects could rest their hands on it to facilitate making responses. Prior to the start of the experiment, silver/silver chloride electrodes were attached to the subjects at the vertex and occipital regions (C_z and O_z in the International 10-20 system; Jasper, 1958) referred to left mastoid (right mastoid ground). Eye movements were recorded from electrodes placed near the outer canthus of each eye. The electrode for the right eye was situated slightly above the center line of the eye and the electrode for the left eye slightly below the center line. This placement primarily recorded horizontal eye movements but may be infiltrated by blinks (Rechtschaffen and Kales, 1968).

Before the start of each test day, a circular patch of the scalp, approximately 1 cm in diameter, was abraded at the electrode sites to insure that the measured impedance between electrodes did not exceed 1.5 Kohms. Signals were fed through high-impedance probes into ac preamplifiers with a bandpass of .1 to 100 Hz. The data then went onto a 1 inch analog tape. At the start of each trial (scenario) the objects were approximately 0.16 cm wide (scale width = 50 ft) and at maximum (no subject response to stop the scenario) approximaely 3.18 cm. Each scenario began at a scale distance of 5 miles from the observer with the objects randomly spaced at altitudes of 1000-1500 ft.

122

The objects moved at a scale speed of 450 knots and the direction of movement at the start of the scenario was randomly oriented in the horizontal plane up to 45 degrees from the line of sight between the objects and the observer. If there was no subject response, the scenario terminated when the target was a scale distance of 0.25 miles from the observer. At a scale distance of 0.5 miles, targets abruptly dove toward the observer (attack run) and drones began to gain altitude. An attempt was made to simulate realistic flight patterns of targets and drones by incorporating the suggestions of a number of pilots into the simulation. A detailed description of movement constraints may be found in the AFOSR 77-3184 annual report, November 1977.

At the start of a scenario, subjects were looking at a blank screen with their hands resting on the response keyboard. When the scenario began, the objects appeared as very small shapes and began "flying" toward the observer. The subject attempted to identify one target (although more than one may be in the clutter) as quickly as possible. When one had been identified, the subject pressed any key on the response keyboard. On the display, movement stopped and each object was immediately replaced by a stationary letter located on the screen at the exact location of the object when the response was made. The subject then typed on the response keyboard the letter which corresponded to the object he had identified as a target. After finalizing his

choice (striking the return key), the screen indicated
whether the response was correct or incorrect and which
letters corresponded to targets and which to drones (the
letters remained in their position on the screen throughout
this feedback). After a 10 sec period, the screen went blank
and the intertrial interval started.

If no response was made, the scenario ran about 45
sec., until the target reached a scale distance of 0.25
miles from the observer. Random intertrial intervals from 5
to 45 sec separated scenarios. These experiments presented
55-90 scenarios per sessin with a 5 minute break after 30
scenarios. Subjects generally took 1.5 - 2.0 hours to
complete a session. Each subject was run in 2-5 sessions
which were spread out over a 3-4 week period (availability
of flight-line personnel was a prime consideration). Each
subject was tested for acuity, depth perception, and ocular
muscle balance with the Armed Forces Vision Tester. None of
these showed any abnormalities.

Results

In general there were few identification errors
(incorrect responses). Together, all subjects responded
correctly to 83.5% of the total of 1898 trials on which a
response was made. There were only 19 trials (1.0%) on which
no response was made. Most of these no response trials

occurred early in the first testing session when subjects were unsure of themselves. Other incorrect responses were attributable to subjects attempting to make a rapid identification and "taking a guess" before they were sure of the target. Since there were relatively few incorrect responses and these were scattered across conditions, the following results are reported for correct response trials only.

Response Data

Figure 24 is a sample of recorded data from one trial. Two latencies are defined in this figure. Latency 1 (LAT 1) is the time from the start of the scenario until the subject makes an initial response which stops the scenario and converts the objects into letters. Latency 2 (LAT 2) is the time from the initial response to the input of a letter identifying the target. LAT 1 is roughly correlated with the scale distance of the target from the observer at the moment of response, however, due to the flight patterns and interactions between targets and drones, the final distance from the observer cannot be accuraely calculated from LAT 1. Distance was available from the computer printout of the results for each trial. Since distance is a more meaningful operational measure than LAT 1, it is used for analysis. LAT 2 may be interpreted as a measure of uncertainty of identification. As confirmed by subject's verbal reports,

latencies were faster when the subjects were sure of their choice.

Figure 25 shows the effects on distance at identification of target/drone ratio and total number of items in experiment 1. Targets in ratios 1/3 and 1/5 approached more closely to the observer than ratio 1/1 before identification. The difference due to ratio, when collapsed over total number of items, was statistically verified (F=4.319; df=2,6; p<.05). Within each ratio there was no significant change as total number of items increased, although the values for ratio 1/1 decreased with increasing number of items. When ratios are collapsed, there was a significant reduction in distance with increasing number of items (F = 4.569; df = 5, 15; p<.01).

Figure 26 is a plot of LAT 2 for experiment 1. In this case there was no significant difference between ratios but a reliable change in latency over total number of items (F = 16.784; df = 5,15; p<.001).

In experiment 1 the total number of objects is confounded with the number of targets. Experiment 2 held the number of targets constant (at 1) and varied the total number of objects over approximately the same range as in experiment 1. Figure 25 plots the distance at identification over total number of objects for experiment 2 (E2 - *). The observed decrease in distance (less rapid identification) with increasing number of items is

126

statistically verified (F = 4.027; df = 5, 15; p<.025). This curve has the same slope as those in experiment 1 but is generally higher (identification is made at a greater distance), though not statistically (F = 0.368; df = 1, 3; p<.9).

Figure 26 plots LAT 2 for experiment 2 (E2 - *). This line is significantly below all data points from experiment 1 (F = 10.634; df = 1, 3; p<.05). The increase over total number of items approaches but does not reach significance at the p<.05 level (F = 2.141; df = 5, 15; p<.1 - F at .05 = 2.90).

Nonpilot subjects were used in experiment 3. In order to compare pilots with non-pilots, conditions were selected from experiments 1 and 2 that matched conditions of experiment 3 (target to drone ratios of 1/1, 3/3, and 1/9). A conservative comparison was made by selecting values from pilots that were closest to the non-pilot values when conditions for the two groups were not identical. This led to selection of 1/1 and 3/3 from experiment 1 and 1/11 from experiment 2.

There was a tendency for pilots to get a slightly higher percentage of correct identifications, but this was a statistically non-significant difference (F = 0.084; df = 1, 3; p<.9).
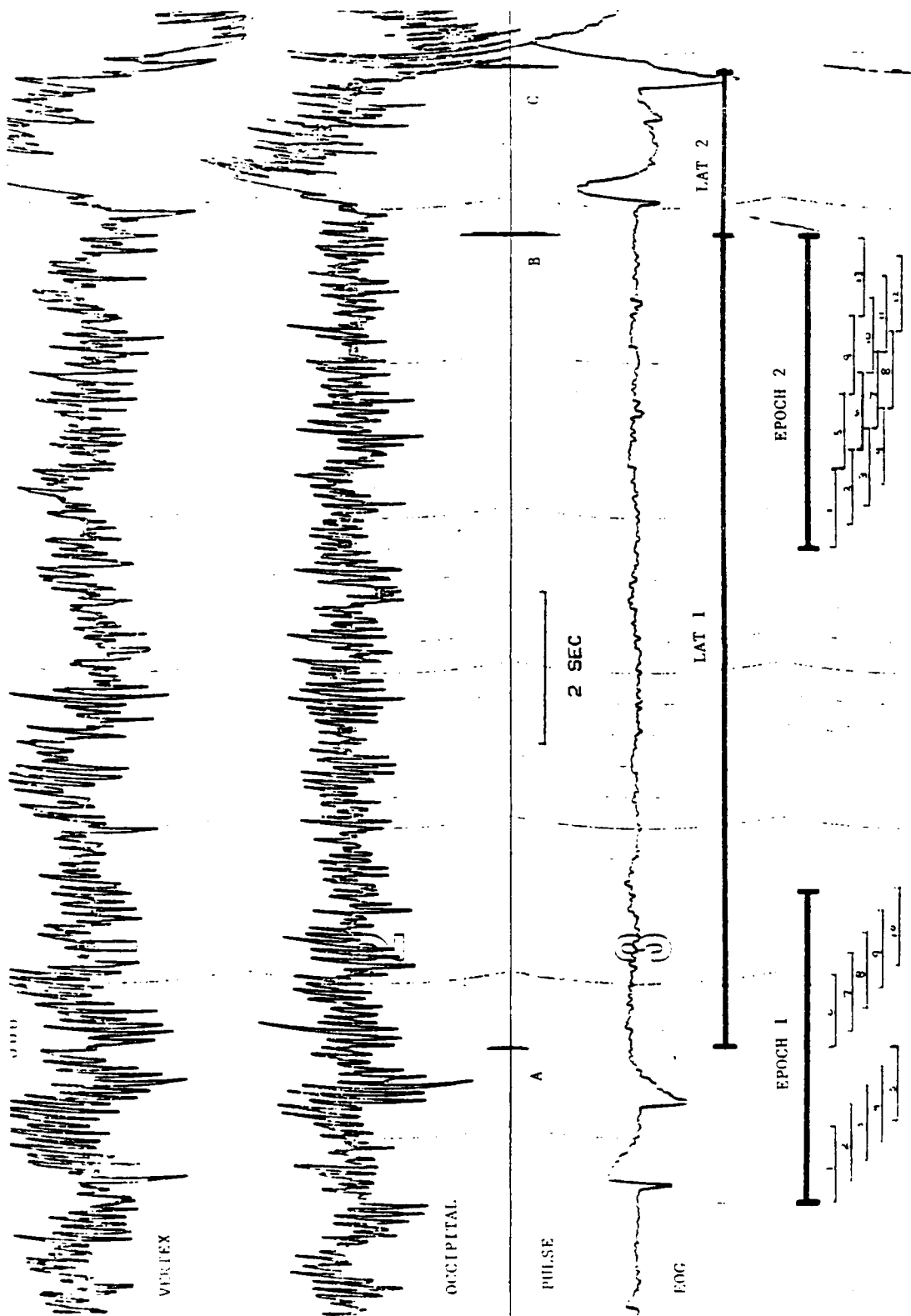
127

FIGURE 24. An example of raw data from 1 trial showing vertex EEG, occipital EEG, EOG, and the pulse channel. On the pulse channel is indicated the start of the scenario (A), the subject's response which stops the scenario (B), and the subject's response which indicates the identification of the selected target (C). Also indicated are the portions of the trial which correspond to LAT 1 and LAT 2. EPOCH 1 and EPOCH 2 are the portions of the trial on which EEG analysis was done. Shown below EPOCH 1 and EPOCH 2 are the 1 sec. epochs which were spectrally analyzed.

VERTEX

OCCIPITAL

PULSE

EOG

A

B

C

2 SEC

LAT 1

LAT 2

EPOCH 1

EPOCH 2
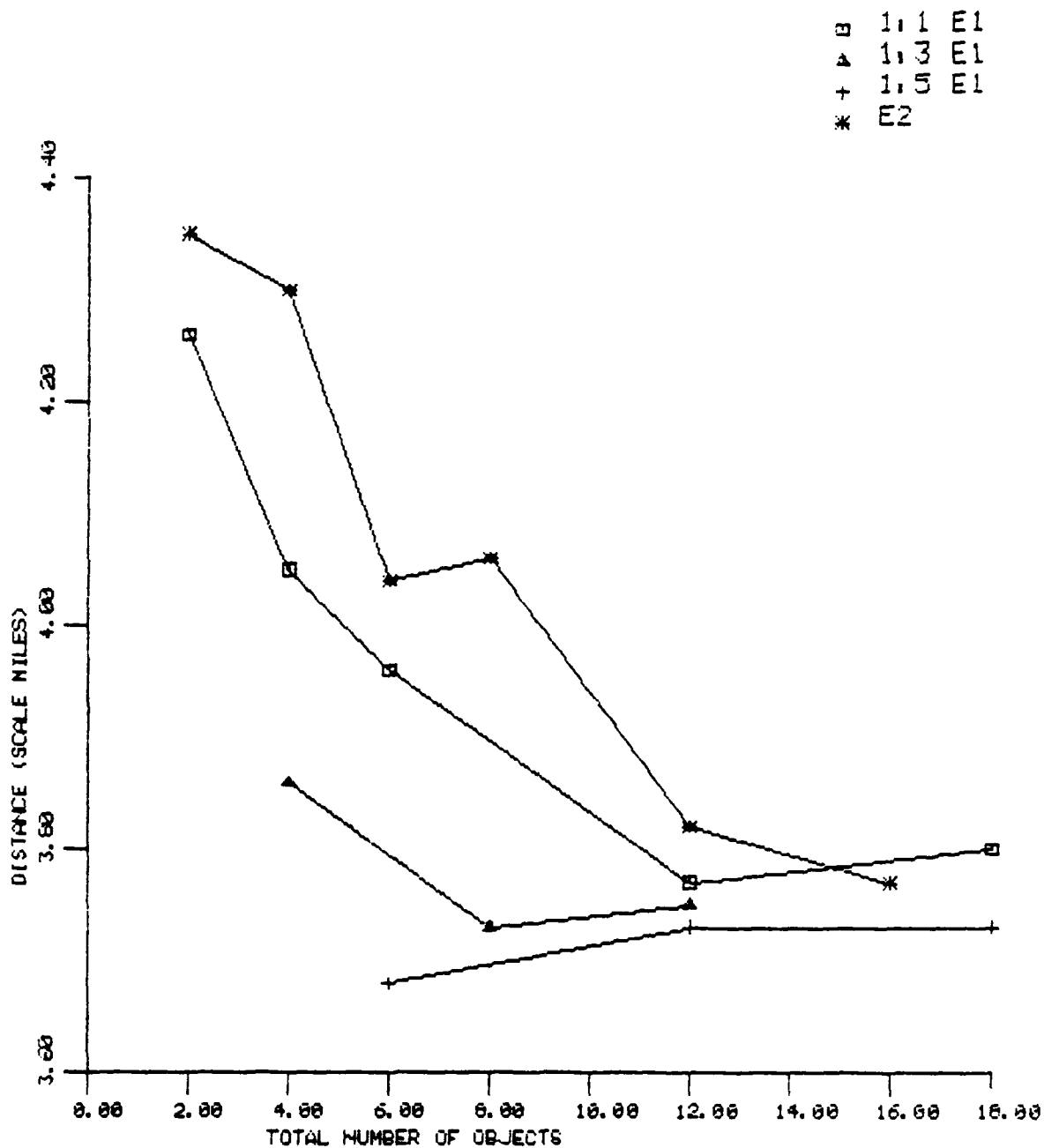
FIGURE 25. Distance from the observer at which targets were identified over number of objects (targets + drones) in Experiment 1 (E1) and Experiment 2 (E2). Experiment 1 ratios are 1:1 (□), 1:3 (▲), and 1:5 (+). Grouping by ratio was not possible in Experiment 2 as only 1 target appeared in each condition.
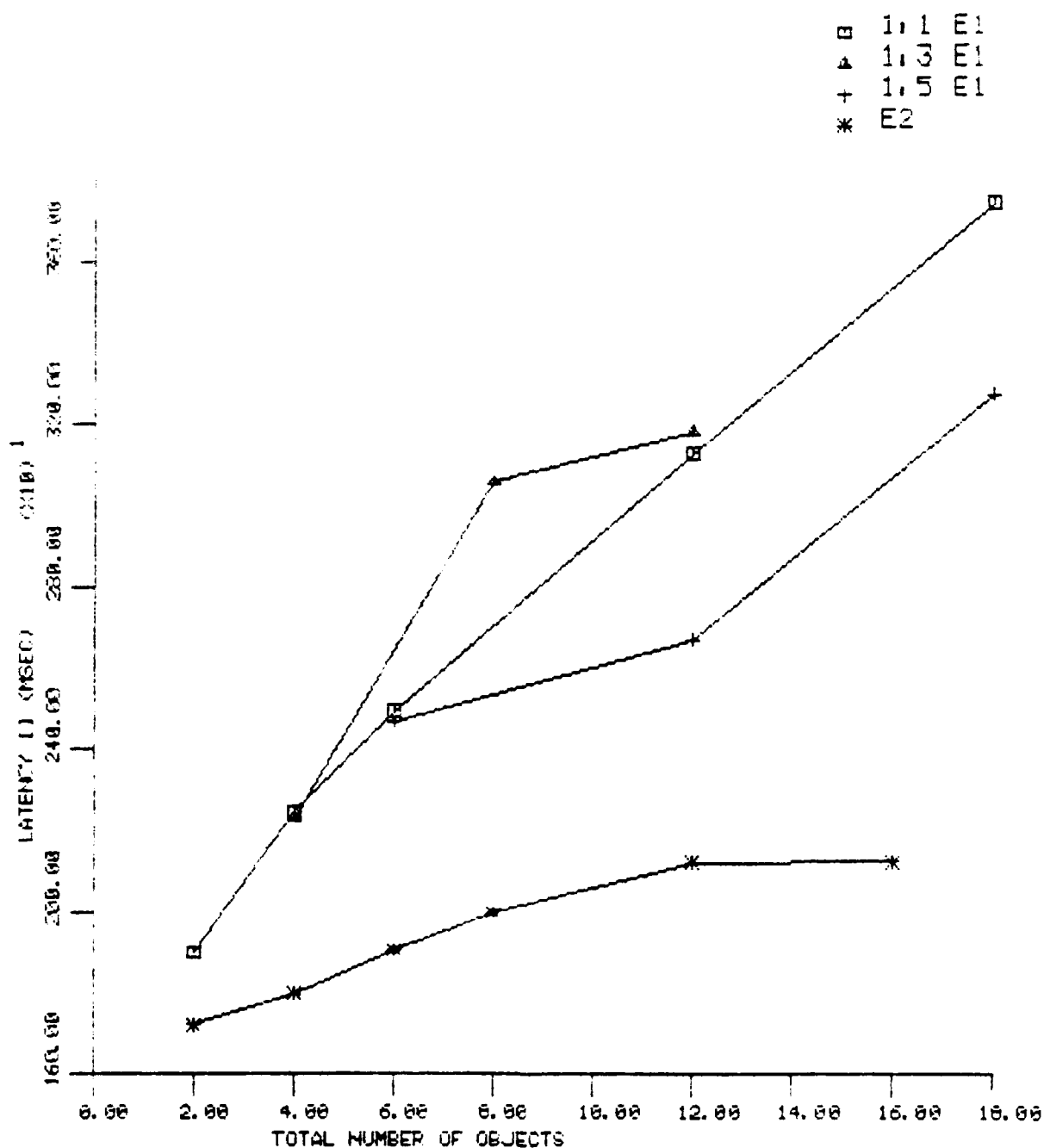
FIGURE 26. Latency 2 over number of objects (targets + drones) in Experiment 1 (E1) and Experiment 2 (E2). Experiment 1 ratios are 1:1 (□), 1:3 (▲), and 1:5 (+). Grouping by ratio was not possible in Experiment 2 as only 1 target appeared in each condition.

130

Table 16 compares distance of the selected target at time of identification and LAT 2 for pilots and nonpilots. Pilots identified targets considerably faster (at greater distance from them) than did nonpilots (F = 15.790; df = 1. 6; p<.01). Confidence in selection of a target (LAT 2) did not differ between groups (F = 0.726; df = 1, 6, p>.9)

Table 16

Means for pilot vs non-pilot subjects.

Targets/Drones	Subjects	Distance (scale miles)	LAT 2 (msec)
1/1	Pilots	4.25	1899
	Non-pilots	2.48	2301
3/3	Pilots	3.95	2493
	Non-pilots	2.20	2936
1/11	Pilots	3.81	2121
1/9	Non-pilots	2.22	1807

EEG and Eye Movement Data

EEG patterns were taken from 2 epoch sets as shown in Figure 24. Epoch 1 was a four second period centered on the start of the scenario (2 seconds prior to the start until 2 seconds after the start). Epoch 2 was a four second period which led up to and terminated with the subject's response.

These epochs were divided into 1-second periods that started 0.25 sec apart from each other. These epochs did not include any overlapping periods at the moment the scenario began in epoch 1. Ten sets of epochs from each subject and each condition were spectrally analyzed and averaged, and the spectral plots arranged in a time sequence in order to make changes in frequency bands readily accessable to the eye. In addition, selected frequency bands (7.0, 8.0, 10.0 Hz) were used as center frequencies for complex demodulation analysis which computed the power at each of the frequencies as a function of time over each 4-second epoch.

Nearly all subjects showed the same eye movement pattern in Epoch 1. Figure 27 shows the spectra of a typical eye movement recording in which there was considerable activity around 1-3 Hz up until the scenario began, then a drastic reduction as subjects focused their

attention on the display. There was a tendency for larger eye movements with greater number of objects on the screen, but due to tne small visual angle occupied by the clutter at the start of the scenario, no large eye movements were needed to scan the display.

EEG patterns from all subjects had one common characteristic — they were usually subject specific. Under no conditions were there consistent EEG patterns between subjects that could be statistically validated. An individual's EEG patterns were typically reproducable for that subject. Even within a subject, reproducable patterns were not observed as a function of target to drone raio or total number of targets.

.

Two examples of patterns in the vertex EEG during epoch 1 are shown in Figure 28. Subject 1 shows relatively low slow wave (1-3 Hz) activity with much larger activity in the alpha band (9-11 Hz). In general, there is an overall reduction in spectral power associated with scenario onset that is most clearly seen in the 1-3 Hz frequency band. Subject 2 shows relatively little alpha activity but a substantial increase in power in the 1-3 Hz range when the scenario starts. This increase is correlated with an eye movement decrease in the same frequency band.
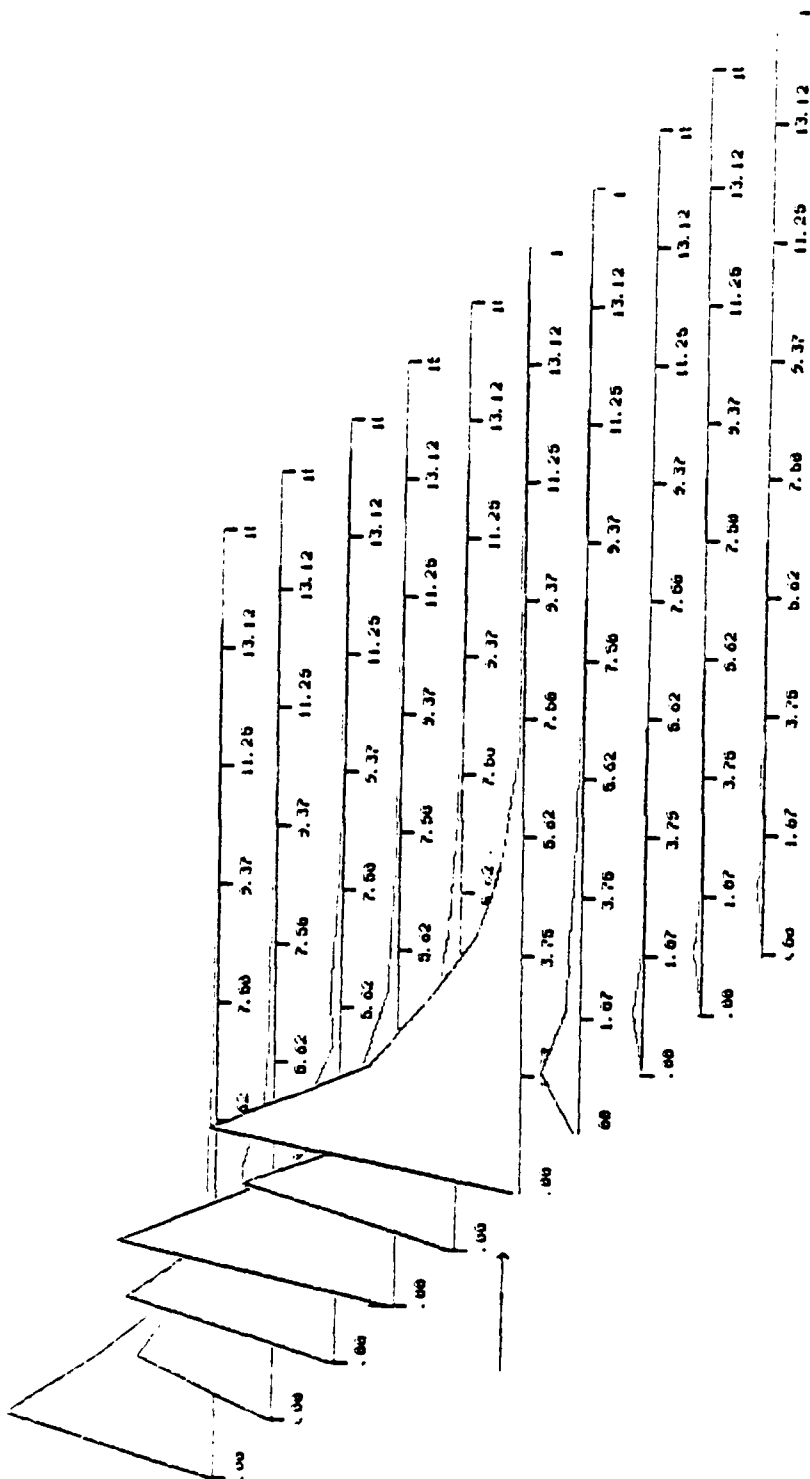
FIGURE 27. Typical spectra of EOG activity during onset of a trial. The arrow indicates start of the scenario. The period shown is 4 seconds starting at the top of the graph.
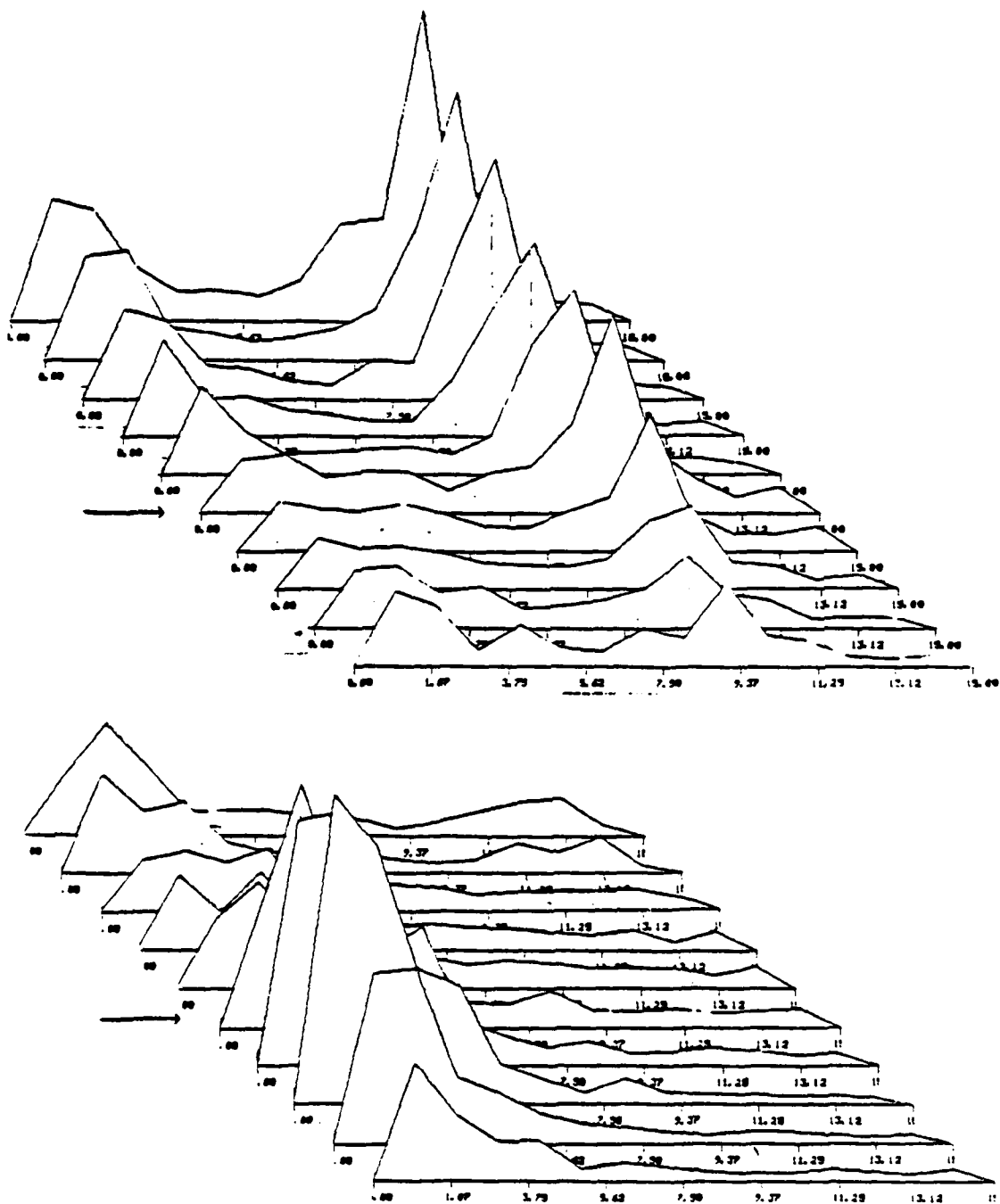
FIGURE 28. Spectra of vertex EEG during onset of a trial for subject 1 (top) and subject 2 (bottom) The arrow indicates the start of the scenario. The period shown is 4 seconds, starting at the top of each graph.
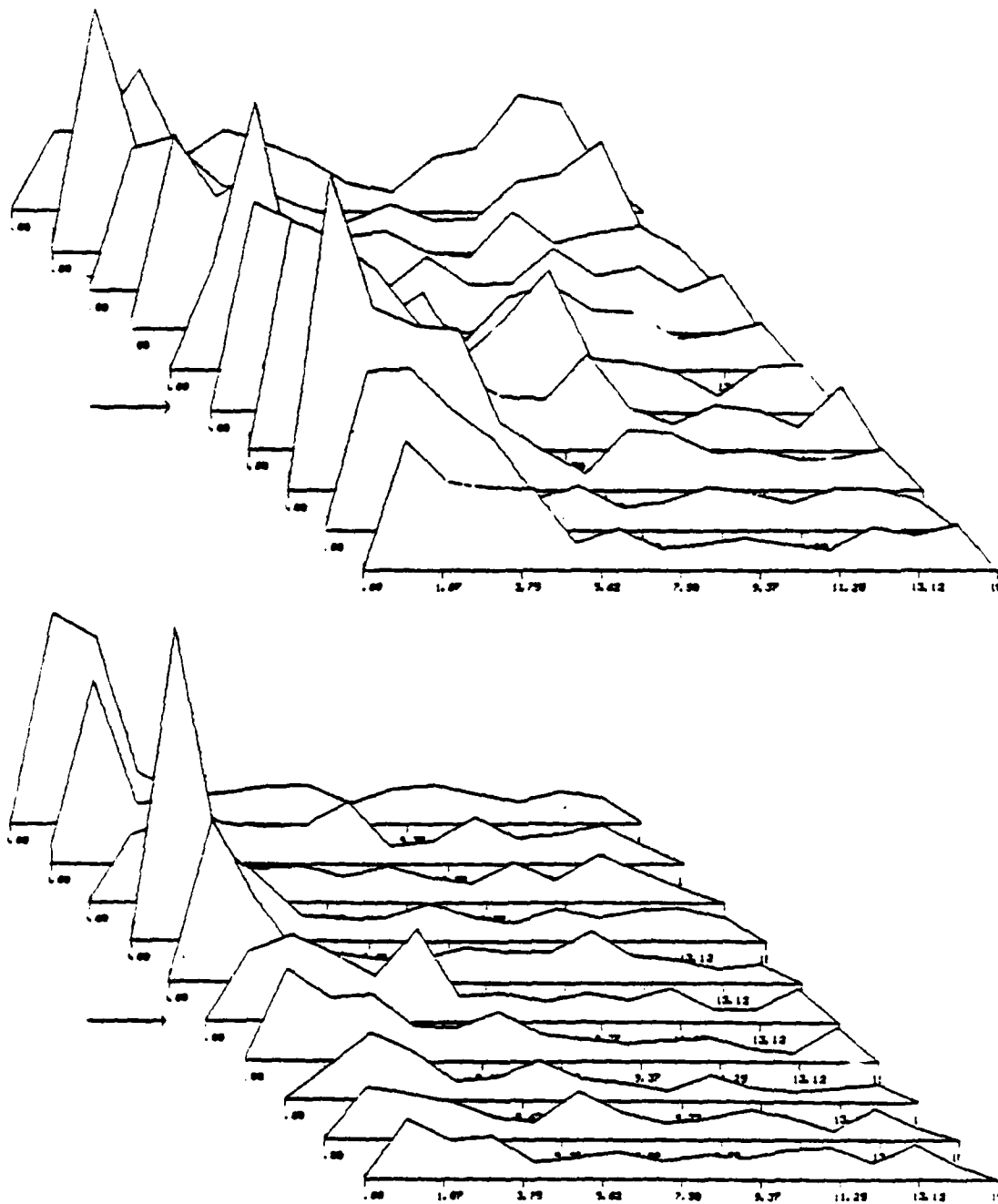
135

FIGURE 29. Spectra of occipital EEG during onset of a trial
for subject 2 (top) and subject 3 (bottom). The arrow
indicates the start of the scenario. The period shown is 4
seconds, starting at the top of each graph.

136

Occipital activity during epoch 1 is shown for 2 subjects in Figure 29. For both there appears to be an overall decrease in spectral power associated with scenario onset. This is easily seen in the 1-3 Hz range for subject 3 and less clearly in nearly all frequency bands for subject 2.

Eye movement activity becomes very individualistic, like the EEG, in epoch 2 (leading up to the subject's response). The 2 plots in Figure 30 show how one subject (#2) exhibited relatively constrained and slow eye movements (1-3 Hz) while the other (#1) had considerable activity out to 10 Hz. This latter subject was one who exhibited very strong alpha activity in all EEG records.

Vertex activity during epoch 2 (Figure 31) seemed to decrease at higher frequencies (9-11 Hz) as the response approached for subject 1 and to increase in that frequency range for subject 2. On the other hand, occipital spectra at 9-11 Hz for subject 1 (Figure 32) increased about 1.5 seconds prior to response, then decreased immediately before the actual response. Subject 2 showed constant high slow wave activity (1-3 Hz) with a small general decrease in power at higher frequencies as the moment of response approached.
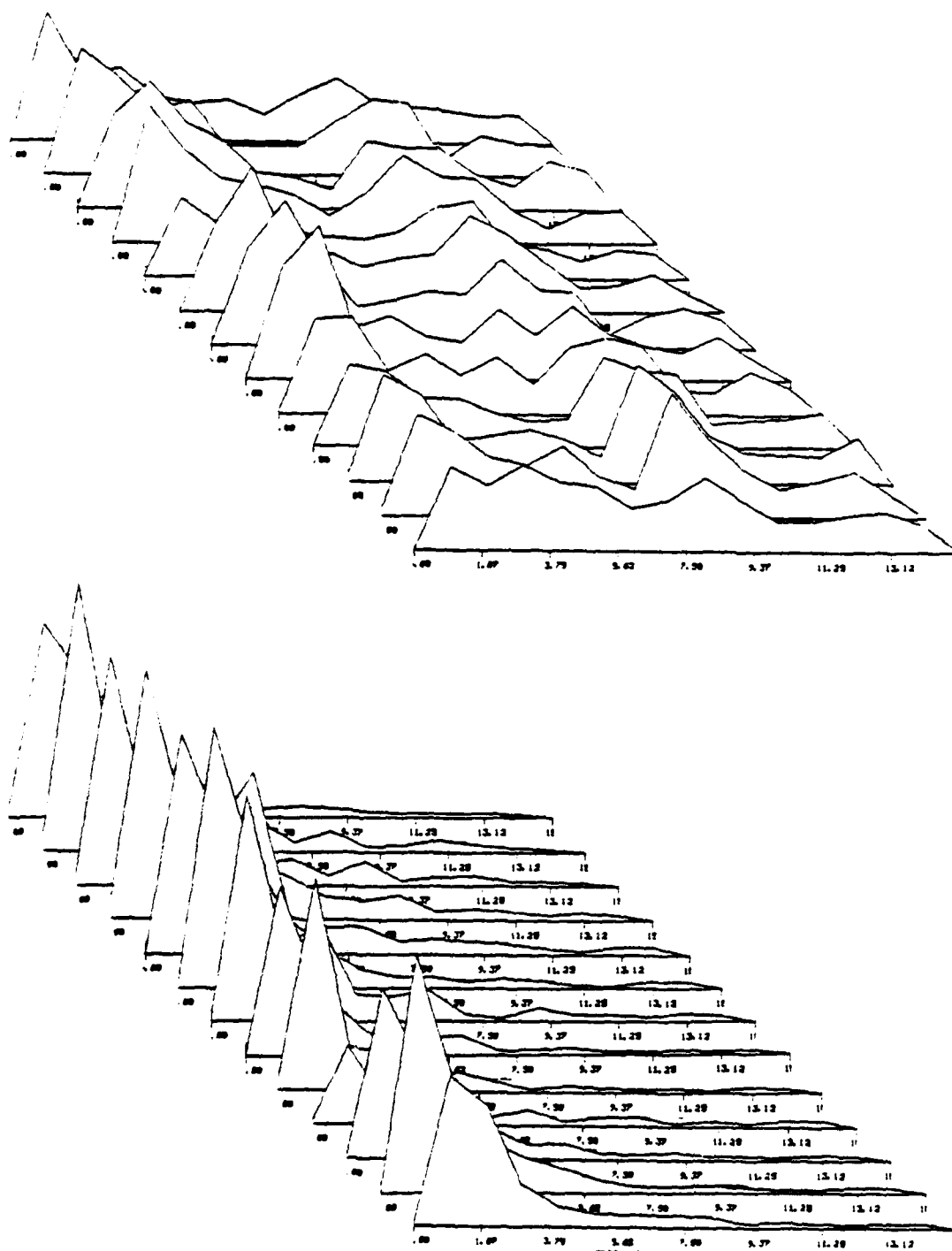
FIGURE 30 Spectra of EDG activity during the 4 seconds just preceeding the initial response for subject 1 (top) and subject 2 (bottom). The period shown is 4 seconds, starting at the top of each graph.
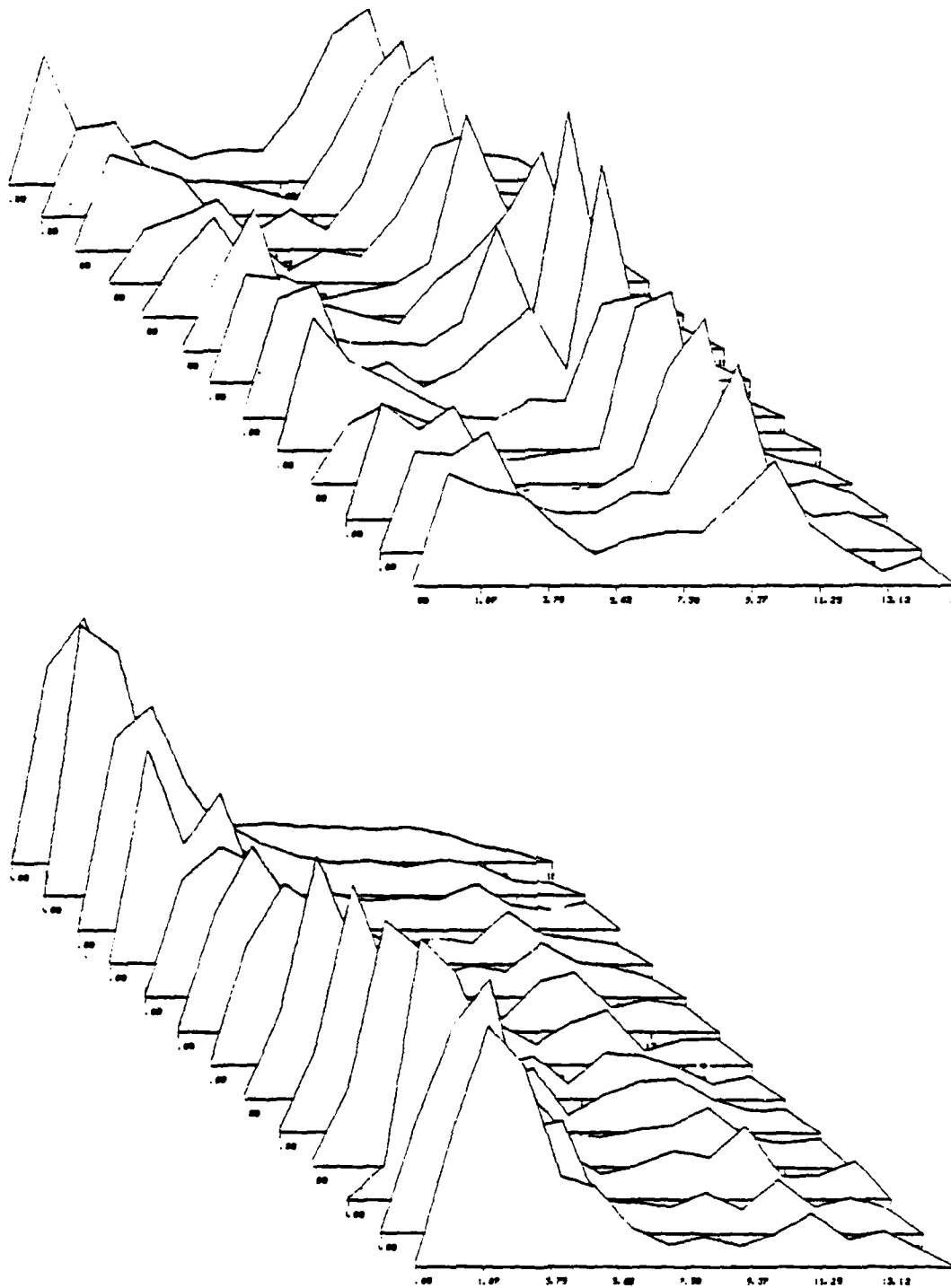
138

FIGURE 31. Spectra of vertex EEG during the 4 seconds just preceeding the initial response for subject 1 (top) and subject 2 (bottom). The period shown is 4 seconds, starting at the top of each graph.
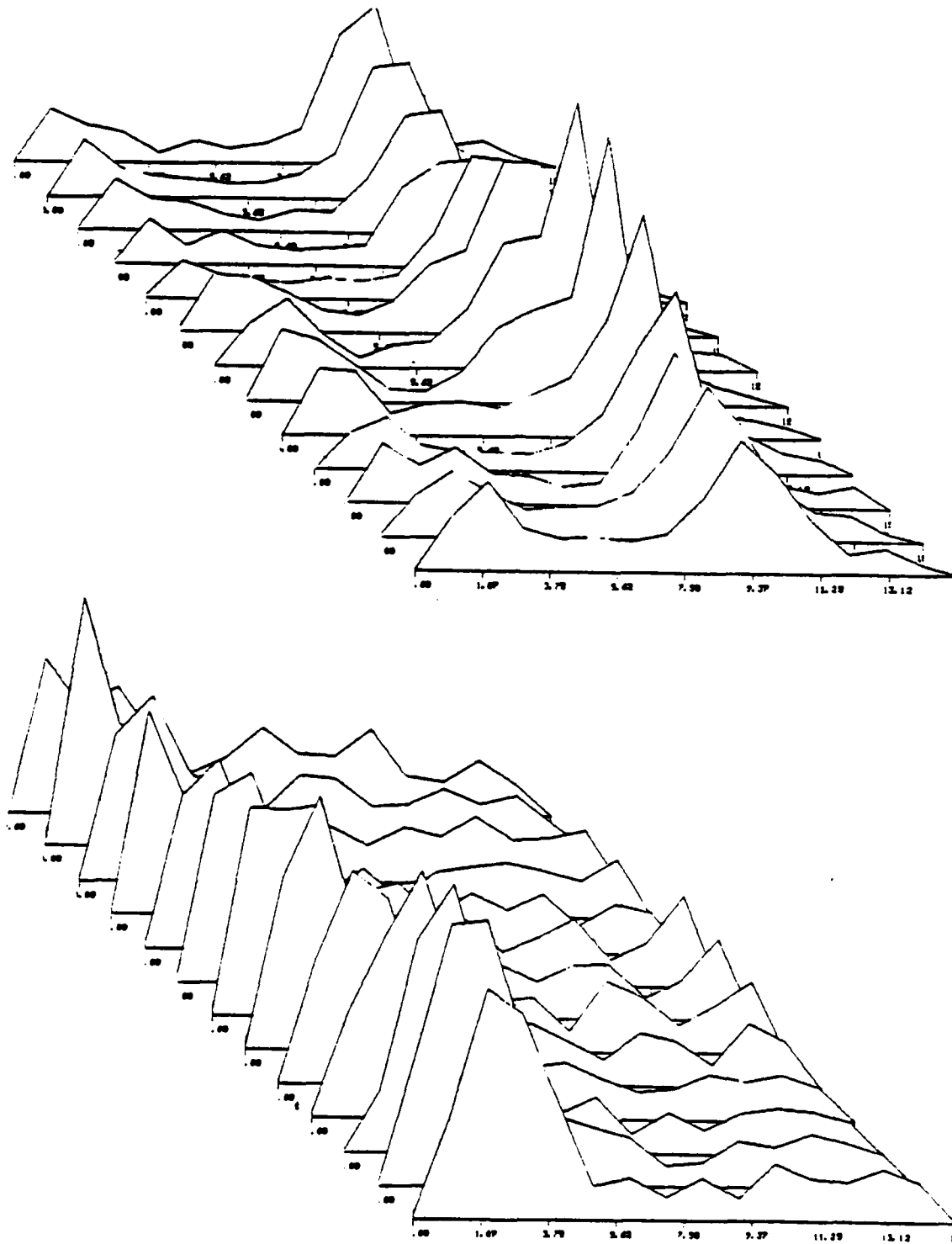
139

FIGURE 32. Spectra of occipital EEG during the 4 seconds
just preceeding the initial response for subject 1 (top)
and subject 2 (bottom). The period shown is 4 seconds,
starting at the top of each graph.

140

Discussion

A powerful research tool for the laboratory study of a wide range of clutter factors has been developed and its operation demonstrated by examining the effects of number of scenario elements and target to drone mix on identification of targets.

Flight line pilots identify targets at a much greater distance from them than do nonpilots in the Clutter task. No other measure, including EEG and eye movements distnguished these two groups, although, on the average, pilots make more correct identifications than nonpilots. There are virtually no differences in the LAT 2 measures which indicates that once the choice is made, both groups are equally confident (or uncertain) in their selection.

Ratio of targets to drones and the total number of items in the clutter both affect the distance at which identification is made as well as the confidence of identification (LAT 2). With greater numbers of items and decreasng ratio, distance from the observer decreases, but confidence of identification also decreases (larger LAT 2). This is undoubtedly at least partially due to subjects scanning additional items before making a final response rather than merely scanning the same objects repeatedly.

Over the range of targets and drones examined, the distance at which identification was made appeared to be reaching a limit around 3.7-3.8 scale miles in experiment 1. Experiment 2 distance did not seem to asymptote. Latency 2 for experiment 1 did not asymptote. For experiment 2 there was no significant LAT 2 increase over the range studied. Additional research with larger numbers of items would be necessary to determine where asymptotes are for these measures.

It is difficult to determine whether ratio or total number of items has a more potent effect on performance from these data. Since performance degradation is statistically very strong with increasing number of items (experiments 1 and 2) but weaker for ratio (experiment 1), a scenario designer should be aware that identification confusion is likely to be maximal when a large number of items are used, no matter what the target to drone ratio, although the most effective ratio is one target matched with a large number of drones. While this result matches intuition, its demonstration eliminates the possibility that an optimal ratio with relatively few items might be as effective as other ratios with many items. It must be remembered that this was a demonstration project to evaluate the Clutter system and the subjects had only to identify one target. A task in which all targets must be identified before any target can "attack" the observer may be more appropriate to some operational scenarios and the optimal parameters may be

142

less intuitive.

A second part of this demonstration project was the examination of EEG and eye movement data to determine if there are patterns in these measures which may be used to predict performance or identify subjects who are good or poor performers. As has been our experience with EEG and eye movement measures applied to cognitive tasks, no computation made on EEG epochs revealed any such predictive ability that could be applied over more than one subject.

A more fruitful approach to independent measures of performance in this and similar simulation performance tasks would be to use the evoked response (ER). Several candidate methods for generating ERs without interfereing with task performance have been investigated in research described elsewhere in this report and could easily be adapted to a task such as this one.

References

Barlow, J.S. and Ciganek, L. Lambda responses in relation to visual evoked responses in man. Electroenceph. clin. Neurophysiol., 1969, 26, 183-192.

Campbell, F.W. and Maffei, L. Electrophysiological evidence for the existence of orientation and size detectors in the human visual system. J. Physiol. 1970, 207, 635-652.

Childers, D. Complex demodulation of visual evoked responses. Electroenceph. Clin. Neurophysiol., 1973, 34, 446-447.

Childers, D. and Durling, A. Digital filtering and signal processing. West Publishing Co., New York, 1975.

Chirlian, P.M. Signals, systems and the computer. Intext, New York, 1973.

Chu, Y. Digital simulation of continuous systems, McGraw-Hill Book Co., Inc., 1969.

Cobb, W.A. and Pampliglione, G. Occipital sharp waves responsive to visual stimuli. Electroenceph. Clin. Neurophysiol., 1952, 4, 110.

Cooper, R., McCallum, W.C., Newton, P., Papakostopoulos, D., Pocock, P.V., and Warren, W.S. Cortical potentials associated with the detection of visual events. Science, 1977, 196, 74-77.

Ebersole, J.S. and Galambos, R. Lambda waves evoked by retinal stimulation in the absence of eye movements. Electroenceph. clin. Neurophysiol., 1973, 35, 39-47.

Evans, C.C. Comments on 'Occipital sharp waves responsive to

visual stimuli'. Electroenceph. clin. Neurophysiol., 1952a, 4, 111.

Evans, C.C. Some further observations on occipital sharp waves (lambda waves). Electroenceph. clin. Neurophysiol., 1952b, 4, 371.

Ford, J.M., Roth, W.T., Dirks, S.J., and Kopell, B.S. Evoked potential correlates of signal recognition between and within modalities. Science, 1973, 181, 465-466.

Gastaut, Y. Un signe electroencephalographique peu connu: les pointes occipitales survenant pendant l'ouverture les yeux. Rev. Neurol, 1951, 84, 640-643.

Gomer, F.E., Spicuzza, R.J., and O'Donnell, R.D. Evoked potential correlates of visual item recognition during memory-scanning tasks. Physiol. Psychol., 1976, 4, 61-65.

Harter, C.M. and White, C.T. Effects of contour sharpness and check-size on visually evoked cortical potentials. Vision Res., 1968, 8, 701-711.

Hillyard, S.A., Squires, K.C., Bauer, J.W., and Lindsay, P.H. Evoked potential correlates of auditory signal detection. Science, 1971, 172, 1357-1360.

Jasper, H.H. Report of a committee on methods of clinical examination in electroencephalography. Electroenceph. Clin. Neurophysiol., 1958, 10, 370-375.

Jeffreys, D.A. in MacKay (ed.) Evoked potentials as indicators of sensory information processing. Neurosci. Res. Prog. Bull., 1969, 7.

Kurtzburg, D. and Vaughan, H.G., Jr. Electrocortical potentials associated with eye movement. Cited in Regan, D. Evoked potentials in psychology, sensory physiology and clinical

medicine. Chapman and Hall Ltd., London, 1972.

Meyers, J.L. Fundamentals of experimental design. Allyn and Bacon, Boston, 1966.

Moise, S.L. and Fields D.A. Complete computer systems for the neuroscience laboratory. Brain Theory Newsletter, 1978, 3(3/4), 136-139.

Nirenberg, L.M., Hanley, J., and Stear, E.B. A new approach to prosthetic control: EEG motor signal tracking with an adaptatively designed phase-locked loop. IEEE Trans. on Bio-Medical Engineering, 1971, 6, 389-398.

Norman, D.A. Memory and attention. Wiley: New York, 1969.

O'Donnell, R.D. Secondary task assessment of cognitive workload in alternative cockpit configurations. Conference on Higher Mental Functioning in Operational Environments, AGARD-CCP/181, Ankara, Turkey, 1975.

O'Donnell, R.D. Contributions of psychophysiological techniques to aircraft design and other operational problems. AGARDograph No. 244, August, 1979.

O'Donnell, R.D. and Gomer, F.E. Comparison of human information processing performance with dot and stroke alphabetic characters. AMRL-TR-75-95, Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Ohio. 45433, 1976 [AD A-024099]

O'Donnell, R.D. and Wilson, G.F. Human sensitivity to high frequency sine wave and pulsed light stimulation as measured by the steady-state cortical evoked response. AMRL-TR, 1980, in press.

Rechtschaffen, A. and Kales, A. A manual of standardized terminology, techniques, and scoring system for sleep stages

of human subjects, National Institute of Health Publication 204, 1968.

Regan, D. Some characteristics of average steady-state and transient responses evoked by modulated light., Electroenceph. clin. Neurophysiol., 1966, 20, 238-248.

Regan, D. A high frequency mechanism which underlies visual evoked potentials. Electroenceph. Clin. Neurophysiol., 1968, 25, 231-237.

Regan, D. and Cartwright, R.F. A method of measuring the potentials evoked by simultaneous stimulation of different retinal regions. Electroenceph. clin. Neurophysiol., 1970, 28, 314-319.

Regan, D. Evoked potentials in psychology, sensory physiology, and clinical medicine. Chapman and Hall, Ltd., London, 1972.

Regan, D. Color coding of pattern responses in man investigated by evoked potential feedback and direct plot techniques. Vision Res., 1975, 15, 175-183.

Regan, D. Steady-state evoked potentials. J. of the Optical Society of America, 1977, 67, 1475-1489.

Rietveld, W.J., Tordoir, W.E.M., Hagenouw, J.R.B., Lubbers, J.A. and Spoor, Th.A.C. Visual evoked responses to blank and to checker- board patterned flashes. Acta physiol. pharmacol. Neerl., 1967, 14, 259-285.

Ritter, W. and Vaughan, H.G. Averaged evoked responses in vigilance and discrimination: A reassessment. Science, 1969. 164, 326-328.

Scott, D.F. and Bickford, R.G. Electrophysiologic studies during scanning and passive eye movements in humans.

147

Science, 1967, 155, 101-102.

Shipley, T., Jones, R. W. and Fry, A. Intensity and the evoked occipitogram in man. Vision Res., 1966, 6, 657-667.

Spehlmann, R. The averaged electrical responses to diffuse and to patterned light in the human. Electroenceph. clin. Neurophysiol., 1965, 19, 560-569.

Spekreijse, H. Analysis of EEG responses in man. Junk Publishers, The Hague, The Netherlands, 1966.

Sternberg, S. Memory scanning: Mental processes revealed by reaction-time experiments. Amer. Sci., 1969a, 57, 421-457.

Sternberg, S. The discovery of processing stages: Extensions of Donder's method. Acta Psychol., 1969b, 30, 276-315.

Sternberg, S. Memory scanning: New findngs and current controversies. Quart. J. exp. Psychol., 1975, 27, 1-32.

Sutton, S. The specification of psychological variables in an average evoked potential experiment. In Donchin, E. and Lindsley, D. B. (Eds.) Averaged evoked potentials: Methods, results and evaluations. NASA-SP-191, National Aeronautics and Space Administration, Washington, D.C., 1969, 247-262.

Viterbi, A. J. Principles of coherent communication. McGraw-Hill, New York, 1966.

Wilkinson, R. T. and Lee, M. V. Auditory evoked potentials and selective attention. Electroenceph. clin. Neurophysol., 1972, 33, 411-418.

Wilson, G. F. and O'Donnell R. D. Effects of steady-state evoked responses on performance and transient evoked responses in the Sternberg task. AMRL-TR, in preparation.